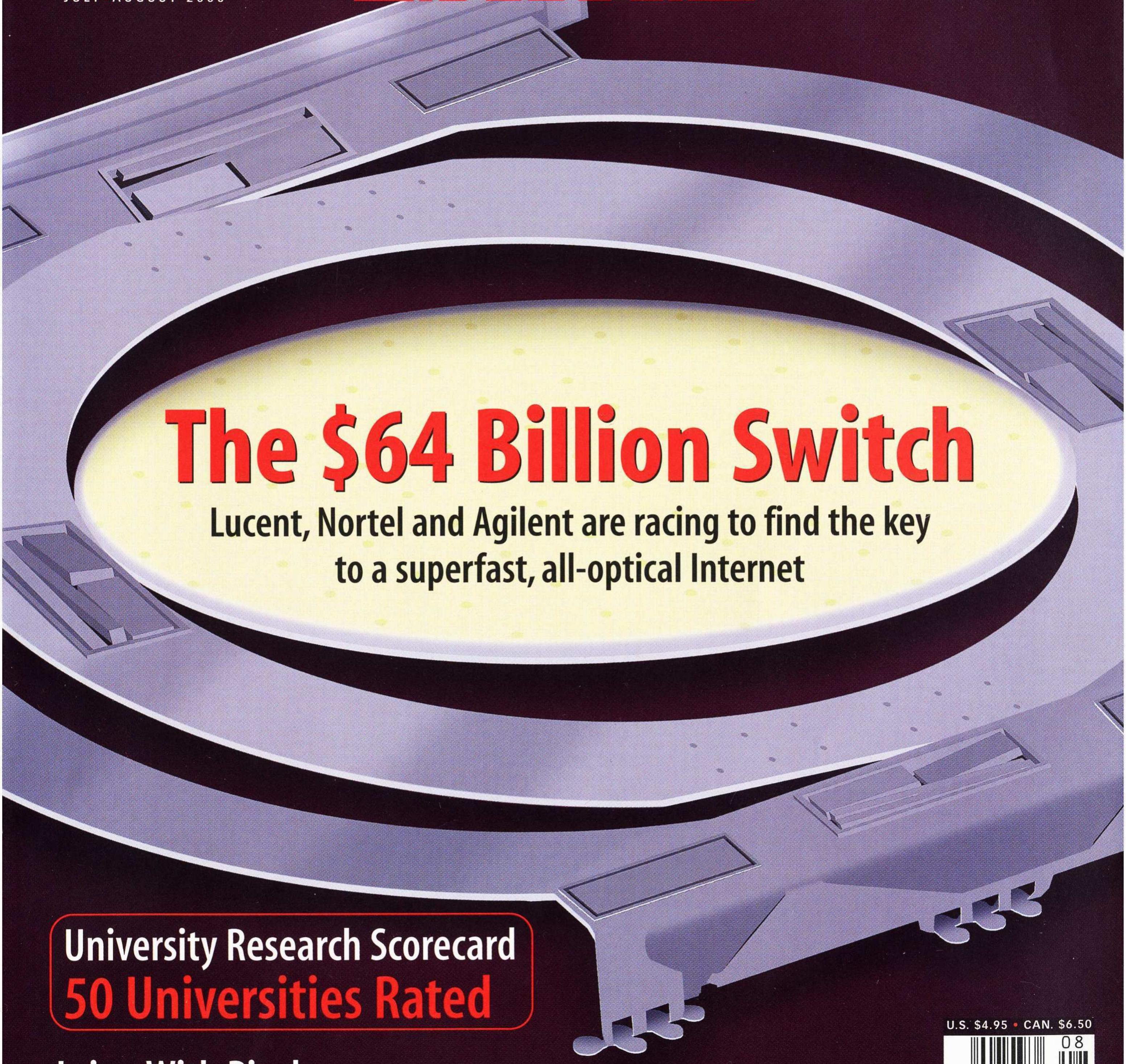
MIT'S MAGAZINE OF INNOVATION

TECHNOLOGY REVIEW

JULY • AUGUST 2000



The $64 Billion Switch

Lucent, Nortel and Agilent are racing to find the key to a superfast, all-optical Internet

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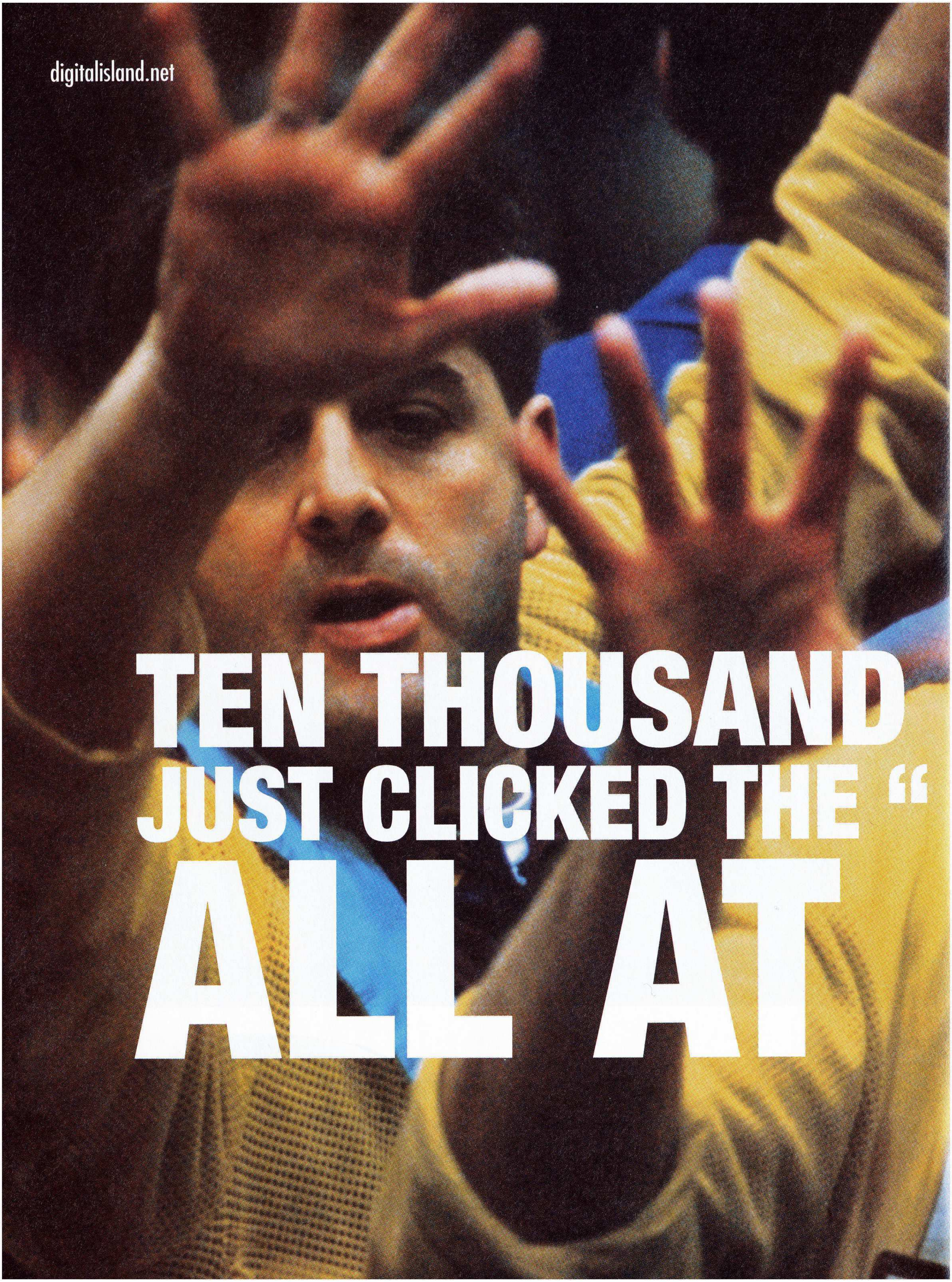
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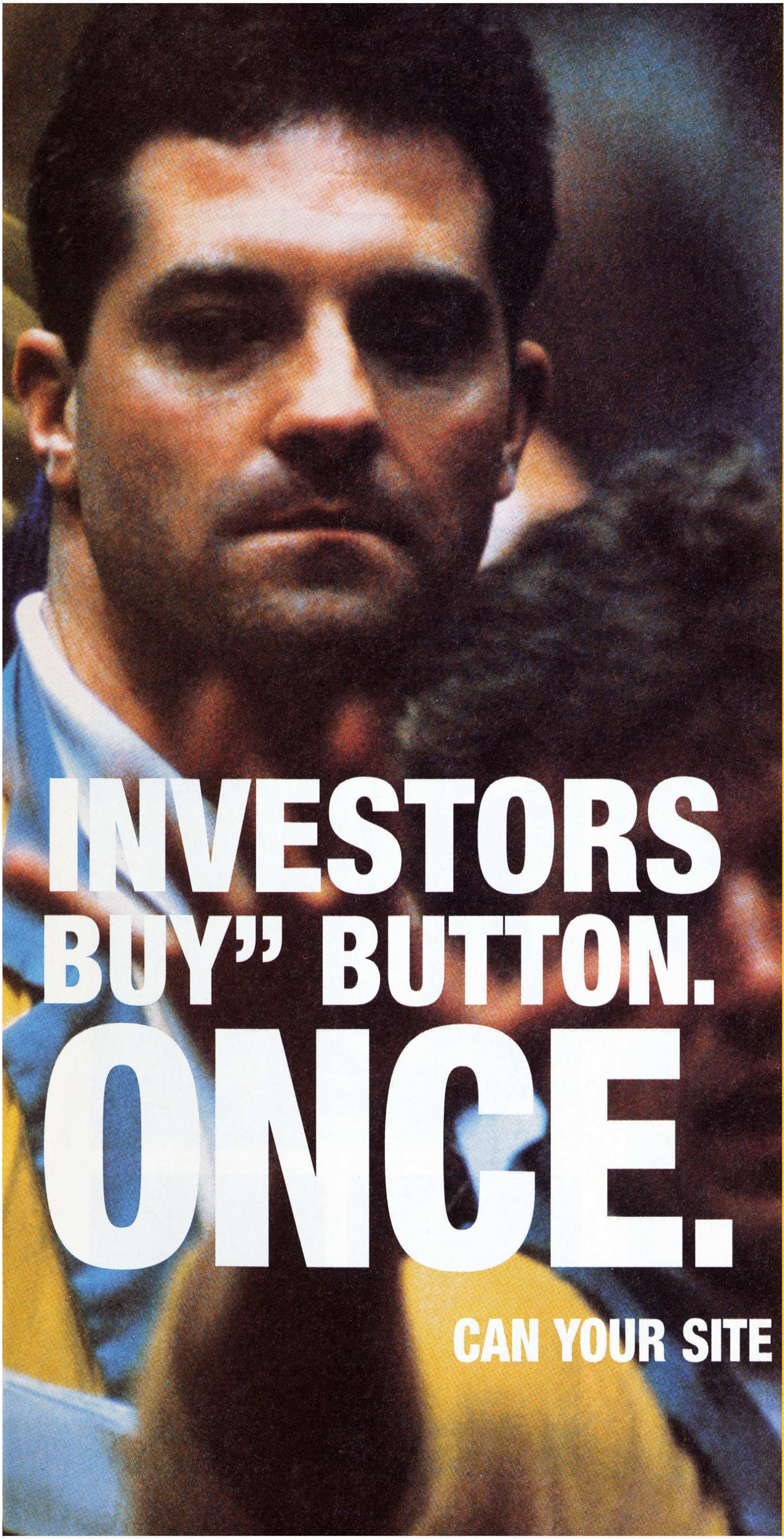

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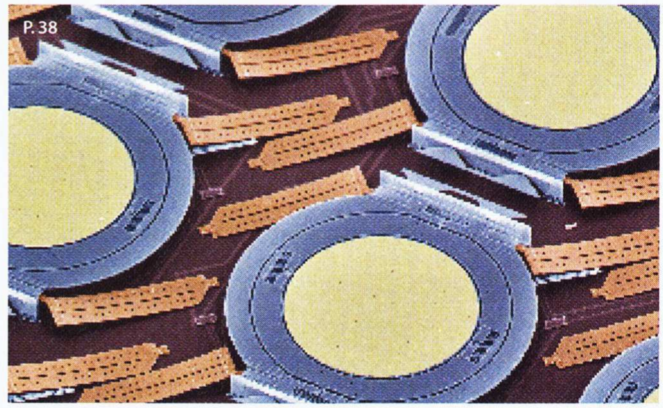
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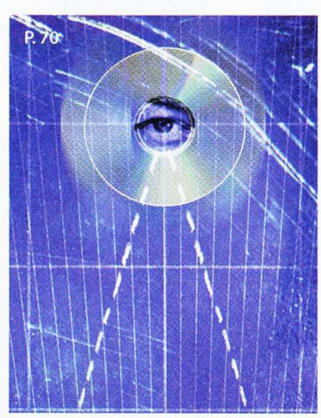
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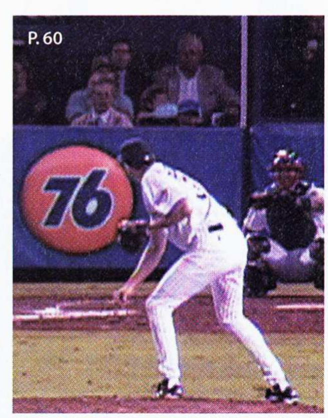
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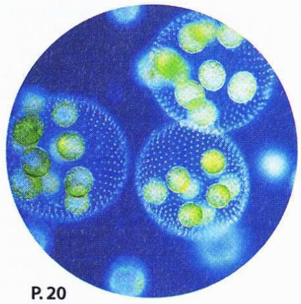

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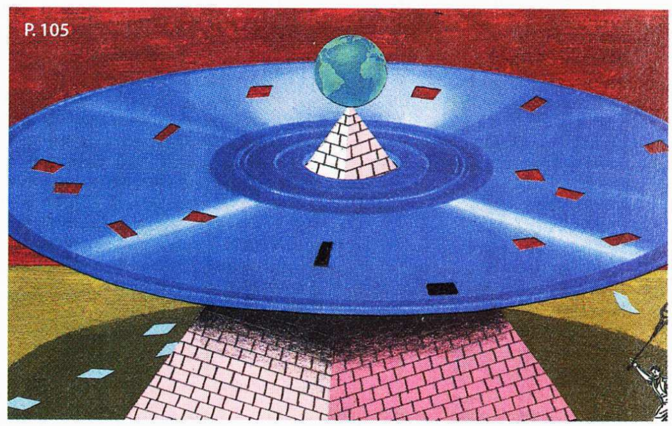

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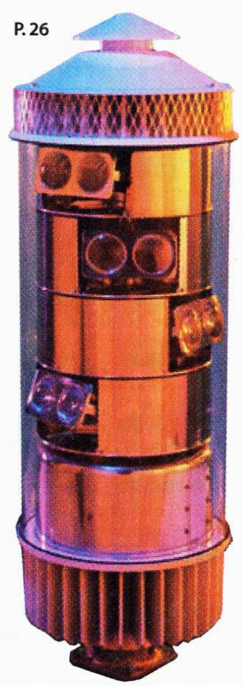

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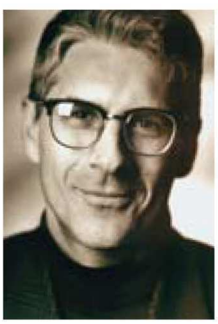
Fantastic Light

"LET THERE BE LIGHT," A VOICE SAID. AND THERE WAS LIGHT. AT LEAST THERE WAS in *part* of the telecommunications network backbone—the many-headed beast that delivers our telephone, fax and Internet services. The problem is that fiber optics have thus far been installed in only part of the system. As soon as the light reaches the big network hubs where it is switched, the signal must be converted to electrons. Electronic switches are bulky, expensive and, by the standards of lightspeed, slow. But until now, there haven't been any optical switches small and fast enough to replace them. This bottleneck is going to become tighter and tighter as our appetite for big-bandwidth applications such as video-on-demand grows.

It's obvious that whoever develops the first reliable all-optical switch is going to cash in. Which is why Lucent, Nortel, Agilent, Corning and a host of startups are hustling to make optical switches. The first commercial versions are reaching the market now—and the markets are taking notice. The day Agilent unveiled its prototype optical switch, the company's stock rose by 47 percent.



TR readers should take note that this exuberance, unlike the dot-com mania, is not irrational. Indeed, the optical switches being developed for telecommunications are only the first step in the "Microphotonics Revolution," as Peter Fairley reports *(page 38)*. After breaking the bottleneck in the telecom backbone, the next step is likely to be extending optical switching to the routers that send our e-mail hither and yon. The result: an all-optical Internet significantly faster than the one we know.

After that, the changes are likely to be on a smaller scale: inside your computer. Over the last couple of decades the processing units inside computers have gained so much speed that they're outrunning the capacity of the wires connecting them to their memory units. These "interconnects" have now become a bottleneck not unlike the one in the telecommunications system. And the solution may be the same: replace electrons with photons. A further wave of the Microphotonics Revolution could be a healthy dose of optical communication injected into the computer itself, with attendant benefits in speed.

We think the Microphotonics Revolution is a key area to watch in the next decade, and you can be sure that as the revolution progresses, *Technology Review* will give you a close-up view. As Fairley has done in his article, we will continue to identify the main technologies, tell you the most important corporate and academic players, and lay out a timescale for specific developments. More light!

—**John Benditt**

Lighten Up

Like the corporate and university labs we cover, the staff of *Technology Review* is constantly trying to improve our product. Sometimes, as when we relaunched *TR* two years ago, the changes are dramatic. Sometimes, as in this issue, they're subtle but significant. To make the magazine easier to read, Art Director Kelly McMurray has lightened the tints we use behind some of our stories. (This paragraph is printed on one of the new tints.) McMurray has also changed our type, making it a shade bigger. The intent of these changes is to make the magazine even more readable. Let us know whether we've succeeded.

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TECHNOLOGY REVIEW

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"You can discount 90 percent of what people are telling you." What a way to start reporting a cover story. Yet that's what a senior telecommunications executive told freelance writer **Peter Fairley** when he started nosing into microphotonics, the optical technology that's shaping the next generation of Internet infrastructure. The market for data routers and switches has become blisteringly hot and hugely profitable, but because technological change is so rapid, Fairley found that many companies are pitching tomorrow's innovations before they happen. "Everyone out there is declaring that they are already installing the all-optical Internet, because if you don't use that terminology today you are dead," he says. "Cutting through the bull was a big part of the challenge." In his story "The Microphotonics Revolution," starting on p. 38, Fairley details what's what in optical hardware. Fairley is a former senior editor at *Chemical Week* magazine.


FAIRLEY

What, exactly, is an e-book? As a seasoned technology journalist, **Steve Ditlea** thought he knew: An e-book is one of those special-purpose handheld computers that still cost too much. Wrrroonggg! The story of how Ditlea clued into "The Real E-books" *(see p. 70)* starts two years ago in a muddy field in the Alpes Maritimes region of southern France, where *TR*'s contributing writer was hiking with a British potter named Eric Rowe. When Rowe complained he couldn't find a publisher for his guide to the geology of ceramics and glazes, Ditlea casually suggested he post his book on the World Wide Web. That was that, until nine months later when Ditlea received a surprise e-mail. Not only was Rowe's book online and selling for $17 a copy, the text had been published in surprisingly simple format—as a PDF file readable on any computer. "I was totally blindsided by this notion of the e-book," Ditlea admits.

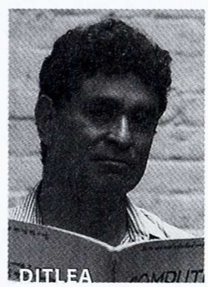
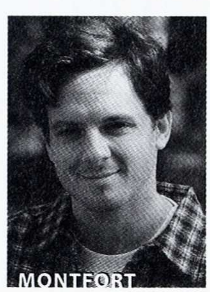

DITLEA

Photo-illustrator **Stuart Bradford** did a great job of capturing our mixed-up notions about e-books in his opening image for Ditlea's story. Part manuscript, part machine, part digital and part drawn, Bradford calls his vision of the e-book "a bastard thing" that represents both a technological idolization of reading and a desecration of it. Bradford acknowledges that his medium, combining photographs, computer effects, found objects and hand drawings, is also a heretical hybrid. For Bradford, photo-illustration works because it can explain technological objects without being literal. "I get called because someone wants an interpretation," says Bradford, who lives north of San Francisco in the town of San Anselmo.


BRADFORD

Most people complain about information overload, but **Nick Montfort** says he's also worried about the opposite problem—every day, countless bytes of the Web's short but rich history as a medium are lost forever. In this issue's Viewpoint, "In Search of Webs Past" on p. 105, Montfort calls on archivists to take action to conserve digital history. Montfort is doing his part: He's begun work on a multimedia textbook anthology of some of computerdom's greatest hits; for instance, software that emulates the long-obsolete Apple II GS computer and lets users play the classic videogame Space War. Montfort is an electronic novelist whose latest interactive epic appears on the Web at www.edreport.com.


MONTFORT

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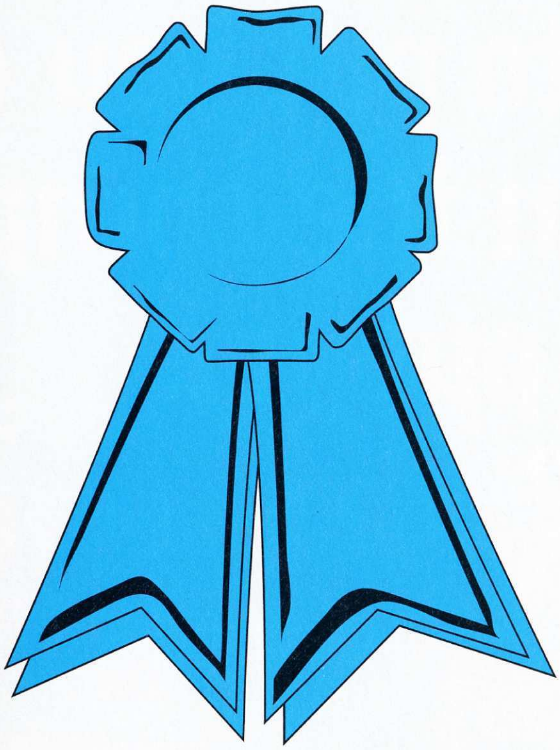

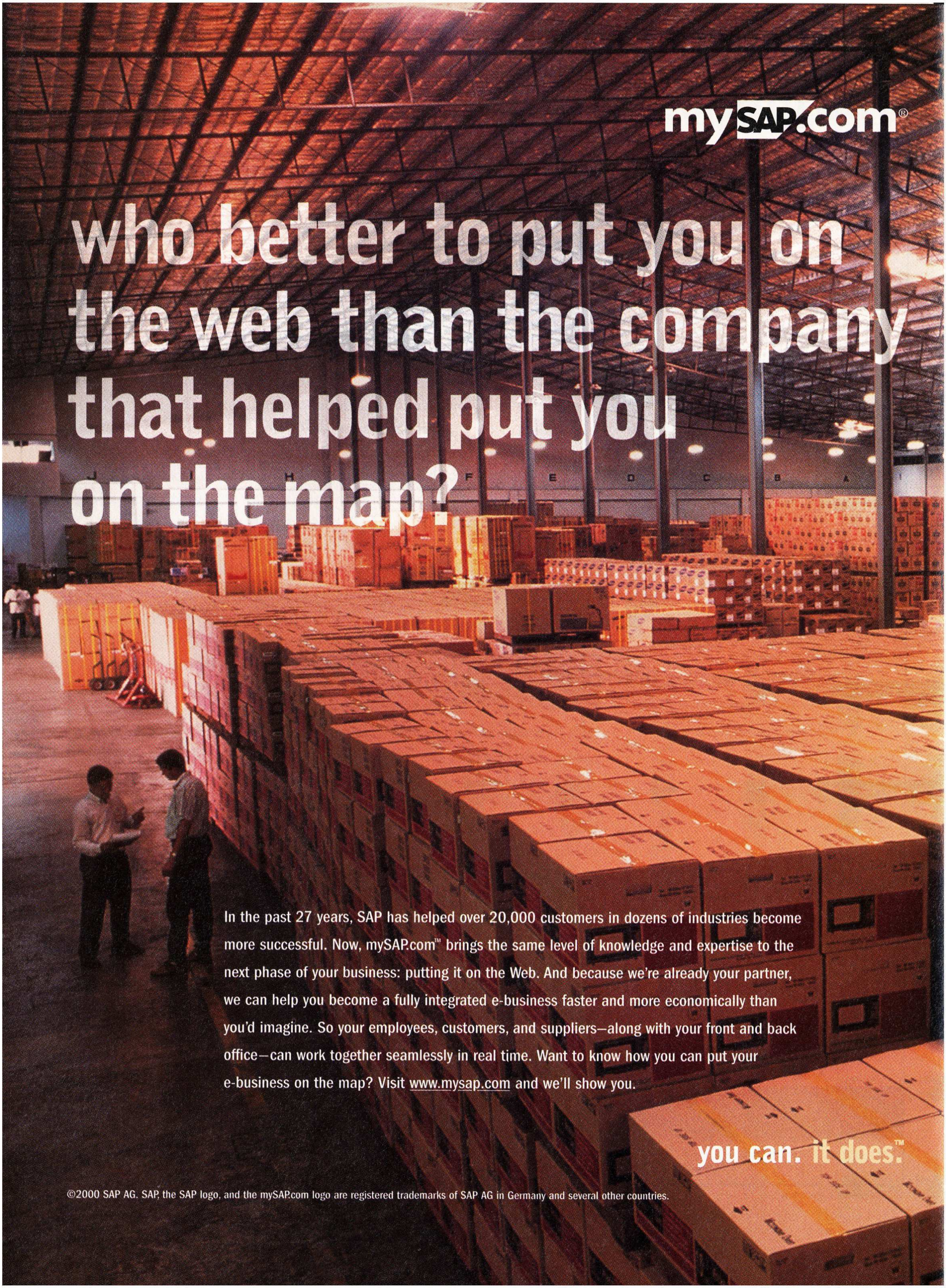
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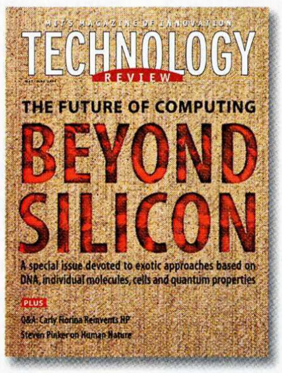
> *"Thank you for publishing such a well-written, understandable and (in true quantum-mechanical fashion) incomprehensible article."*

More Moore

THERE ARE MANY WAYS THAT COMPUTERS could continue to be improved, without relying upon squeezing more transistors onto chips ("Beyond Silicon" Special Issue, *TR* May/June 2000). When Moore's Law grinds to a halt, computer scientists and engineers get to work designing chips that compute with ever more efficient and clever algorithms. Software engineers can write operating systems and applications that squeeze every last bit of power out of the available devices. And improvements in network and Internet bandwidth do not depend entirely on transistor density, so computing power can continue to increase as superfast connections allow users to make use of idle processor time all over the network.



BRADLEY DEMAREST
Salt Lake City, UT

YOUR SPECIAL ISSUE DID NOT COVER ONE way to get more speed and abilities from current technology: massively parallel computers, etched on a single chip. The computer industry has been locked into the Von Neumann architecture, where computers do one thing at a time. It has been cheaper to make smaller, faster chips than to design a radically different architecture. Now that they can no longer make the chips much smaller, chip makers should explore the potential of massively parallel computers on a single chip, made such that any number of these connected chips can work together as one.

Of course designing the circuits, programming languages, compilers and software for these machines will be challenging and expensive. But I believe it has a higher chance of succeeding than the alternatives mentioned in your articles.

DAVID MUSICK
Salt Lake City, UT

I AM SURPRISED THAT CHARLES MANN said that Kirby received no prize for inventing the integrated circuit ("The End of Moore's Law?" *TR* May/June 2000). He and Robert Noyce received the Draper Prize from the National Academy of Engineering, a prize sponsored by Draper Laboratory, a former affiliate of MIT. The NAE, at least, considers this the engineering complement to the Nobel Prizes. Maybe *Technology Review* doesn't!

ROBERT PLUNKETT
Minneapolis, MN

CHARLES MANN STATES THAT, in 1958, "Transistors, diodes, capacitors and other now-familiar electronic devices had just been invented." But diodes had been in common use for decades in radios, both vacuum-tube and "solid state" types. Capacitors go much further back (to Leyden jars). Please do not mislead your younger readers into thinking that everything electronic was invented in the second half of the 20th century.

DAVID P. KELLEHER
Falls Church, VA

Mann responds: *Just as Messrs. Demarest and Musick say, there are many ways that computing might progress after "Moore's Law grinds to a halt." But all of them are difficult—look at Microsoft's long struggle to eliminate the last vestiges of MS-DOS—and most are untried. Massive parallelism, for instance, requires wall-to-wall rewrites of software—a cost so high that customers refused to do it for Danny Hillis' Thinking Machines, which thereupon went belly-up. To Mr. Plunkett: I had thought "prize" obviously referred to the Nobel in the previous sentence; if this wasn't evident, I welcome the clarification. My point was that Mr. Kirby didn't become a standard historical referent the way Mr. Shockley did. Mr. Kelleher is completely on target. I had thought about listing some of the many types of transistor, but then—oh, what can I say? I goofed.*

We welcome letters to the editor.

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Please include your address, telephone number and e-mail address.
Letters may be edited for clarity and length.

Quantum Delight

REGARDING M. MITCHELL WALDROP'S "Quantum Computing" (*TR* May/June 2000): Thank you for publishing such a well-written, understandable, fascinating and (at the same time—in true quantum-mechanical fashion) incomprehensible, mind-boggling and utterly strange article. Pure entertainment!

MICHEL BENEVENTO
Amsterdam, Netherlands

Copywrong

I HAVE TO AGREE WITH RICHARD STALLman ("Freedom—or Copyright?" *TR* May/June 2000) that copyright has gone too far. As an amateur musician I think Napster and MP3 could only do me good. Given the choice between languishing in obscurity while trying to get a record deal or having my songs circulating as MP3 I know which I'd choose. On the off chance that someone out there likes my music I might get a few gigs out of it.

PHILIP WARD
Edinburgh, Scotland

STALLMAN HAS MISAPPREHENDED THE fundamental nature of copyright if he thinks it was originally just an "industrial regulation" on publishers. Article I, Section 8 of the U.S. Constitution says copyrights were intended "To promote the Progress of Science and useful Arts, by securing for limited Times to Authors and Inventors the exclusive Right to their respective Writings and Discoveries." In other words, a good ole capitalist solution to protecting authors and inventors.

But apparently, now that the digital age has arrived, Mr. Stallman feels that there is no need for authors to be protected just because it's really easy to copy that author's work. The same argument can be made for stripping copyright from all music CDs, movies and software in favor

of a vague honor system. Of course, there wouldn't be a lot of new music, movies or software produced if the artists and programmers had no protection against people stealing their work.

STEPHEN STERNS
New York, NY

Human Comforts

STEVEN PINKER PUT HIS FINGER ON A key fact of life: We are indeed humans ("Life in the Fourth Millennium," *TR* May/June 2000). This will certainly mitigate most of the possible futures many are busy pondering. As we move toward a world of transparent, interconnected societies, where most things will be open to public view and hence public influence, his words of wisdom—that it will be human nature that drives the future—are comforting.

BOB RAGER
Silver Spring, MD

AS STEVEN PINKER SO CORRECTLY HIGHlights, emotion and humanness are largely a product of the brain's architecture and its use of the senses. But a millennium of research could change the brain.

Current research and the commercial use of modified animals of various species will continue, regardless of local concerns about the effects. Eventually, the nervous system will be included as a target of genetic manipulation, and the ability to modify the "mind" will mature.

What happens when a successful brain and nervous system manipulation occurs? Almost certainly, the emotional and sensual architecture would be targeted. Should such a genetic variant become viable, the "humanness" of this new subgroup will not so easily be defined.

RUSS LISLE
Kenilworth, NJ

I LOVE TO READ MY SON'S *TECHNOLOGY Review* and learn about the latest amazing technology. But the most earth-shaking event yet was mentioned in the introductory paragraph of Steven Pinker's essay describing what we see at the opening of the third millennium—"patriarchy [has] vanished from vast expanses of the planet."

This is news to me and I would love to see an in-depth article in a future issue. Checking your own list of authors, staff,

review board and index to people in articles for gender balance didn't indicate that it has vanished from this spectacular piece of the planet.

JUDY HELFAND
Kenwood, CA

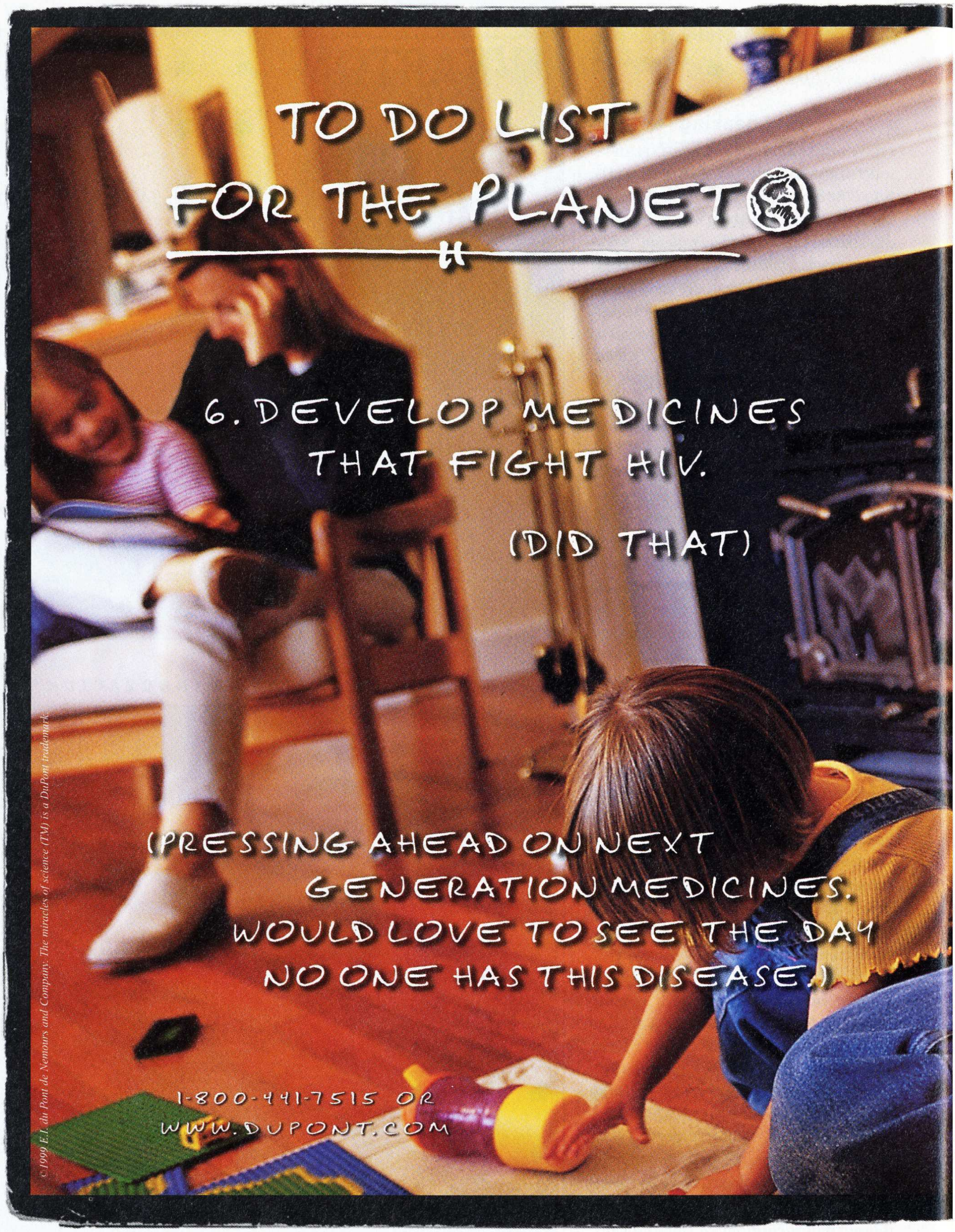
Not Speaking

I HAVE MUCH RESPECT FOR MICHAEL DERtouzos, but I don't think speech recognition ("Speech and Vision," *TR* May/June 2000) will bloom, given the following drawbacks: In noisy environments, especially crowds, even the best speech recognition may never work; there is no security in cases where a topic under discussion is confidential or personal; it is intrusive in public areas and social environments; it is slow when used in interaction control; even the best speech recognition can't claim to be 100 percent error-free because of the nature of the human voice; and speech recognition is language-specific, hence there is no general standard approach in control.

XIN CHONG
Kent Ridge Digital Labs
Singapore

Dertouzos responds: *Your first three points are also valid in people-to-people conversations, and haven't yet discouraged us from speaking to each other. The fourth point is not valid: Current systems at the Lab for Computer Science (LCS) answer spoken queries in real time. On your fifth point, accuracy, currently in the 95 percent range, is lower than that in human-to-human conversations (99.9 percent), but not low enough to make speech systems unusable. Human-machine dialogue catches and corrects errors before they cause trouble. On your last point, Victor Zue's team at LCS has constructed speech systems in English, Mandarin, Japanese, Spanish and German. The absence of a general approach does not preclude the potential utility of speech systems in any of the world's languages. And don't forget that, in time, spoken-language systems will improve, as they have steadily done for the past decade.*

Correction *In the article "Quantum Computing"* (TR *May/June 2000) David Cory is incorrectly identified as a Harvard University NMR expert. In fact, he is a professor of nuclear engineering at MIT.*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Drug Cloud

Anybody who's used an inhaler to treat asthma or allergies is familiar with the medicinal aftertaste. That taste is more than an annoyance—it's a sign that a portion of the drug is going to waste in the back of the throat rather than in the lungs where it's needed. Battelle Pulmonary Therapeutics—a company spun off in April from Battelle Memorial Institute in Columbus, Ohio—is aiming to deliver inhalable drugs more efficiently with new "electrohydrodynamic," or EHD, aerosol technology.

EHD devices use voltage, rather than pressure, to create a "soft cloud" of aerosolized drug. The patient inhales the cloud, rather than having aerosol shot into the mouth at a velocity that propels drug particles against the throat. The new company believes EHD technology will be valuable against a number of respiratory diseases and infections, including bronchitis and pneumonia. As *TR* went to press, the startup had signed two licensing agreements—one to commercialize an anti-viral device—and was working on several other deals.

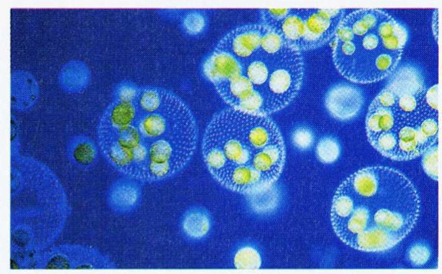
VITO ALUIA

Snackbot

Welsh researchers are making robots that they hope will thrive in the refrigerated environments of the British snack food industry. The vision-endowed machine devised by Jem Rowland and Mark Lee of the University of Wales in Aberstwyth first examines a finished food product. The robot then makes a replica, using image processing to figure out which ingredients to fetch in sequence. Beyond building a better burrito, Rowland and Lee see their work as a step toward mass customization. Their robot would spare programmers from having to write code specifying that two slices of tomato and a pickle belong on every robo-sandwich. The Wales team is working in collaboration with three U.K. food companies—Solway Foods, Rutland Handling and R.F. Brooks—and has demonstrated the robot with simulated food. Rowland and Lee have expressed no plans to develop a home version that auto-assembles sandwiches in the kitchen fridge.

Industrial-Strength Algae

To you, it might be green pond scum. But to some researchers, algae is a vehicle for making key pharmaceutical and industrial compounds. A recent patent could give one company a virtual corner on the biotech algae market. The patent, issued to Martek Biosciences of Columbia, Md., outlines a process to grow non-algal genes in algal cells. The process takes place in a few hours, in contrast to the months it takes to introduce genes into transgenic crop plants like corn or tobacco. The process could also help model the large-scale production of chemicals in crops in fast-growing algae. Martek is working on algal production methods for docosahexaenoic acid, a baby formula ingredient that aids mental development.

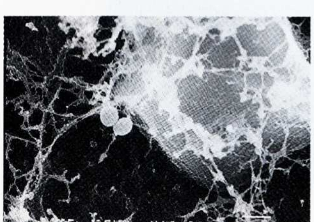


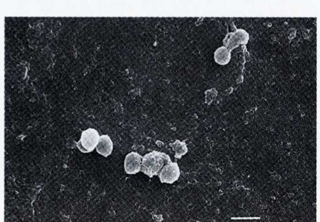
SPIKE WALKER/TONY STONE IMAGES

Fast-acting pharma-factory?

Dissolve to Solve

Hospitals are dangerous places. About 2 million patients a year acquire new infections in them, according to the U.S. Centers for Disease Control and Prevention. A major cause is bacterial contamination of urinary catheters, breathing tubes and implants—a situation made more difficult by the fact that some bacteria form tough antibiotic-resistant films on such devices. University of Texas Health Science Center biomaterials researcher H. Ralph Rawls is developing a nontoxic polymer coating that slowly dissolves in bodily fluids. The coating could be applied to almost any object doctors put into the body. As the polymer dissolves layer by layer, it frees surface-attaching bacteria; this process prevents the formation of a bacterial film and makes the germs susceptible to therapeutic drugs and the immune system. The longer the expected contact between the instrument and the body, the thicker the polymer coating. This summer, Rawls plans to add another function to the polymer by incorporating drugs that encourage tissue repair; he hopes the material will be available clinically in three to five years.





H. RALPH RAWLS

Bacteria thrive on untreated surface (left), but not on polymer coating (right).

Mug Shot Maker

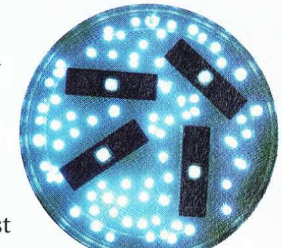
Surveillance cameras often capture a criminal act but produce pictures too fuzzy for the perpetrator to be identified. New software developed by doctoral student James Robinson at Staffordshire University in the U.K. could tighten up this hole in the law enforcement apparatus. The software stitches together several of the blurry still-frame images that have been captured on security camera film and creates a three-dimensional model of the mischief-maker's face. Pivoting this 3-D mug shot, and enlarging the image, produces a clear view. The software also marks key features such as the outlines of the eyes and mouth. Robinson hopes to license the technology to manufacturers of imaging systems.

Beaming Smile

Visiting the dentist isn't just a pain in the jaw—it's also a pain in the pocketbook. Clinical physicists at the Glasgow Dental Hospital and School in Scotland are helping to reduce both types of pain with a carbon dioxide laser that drills tooth cavities without burning the surrounding gums and teeth.

The CO_2 laser's infrared wavelength is ideal for the job because it is readily absorbed by the tooth's dentin and enamel. To avoid cracking of dental tissue around the drilling site, the system uses short pulses of light instead of a continuous beam. Because CO_2 lasers are a well-established technology, the makers of the new drill, John Whitters and Ronald Strang, claim it will be significantly cheaper than today's dental lasers—solid-state systems based on erbium embedded in a crystal of yttrium aluminum garnet, or YAG. The scientists have teamed up with an undisclosed laser manufacturer and plan clinical trials later this year.

Glow Bugs



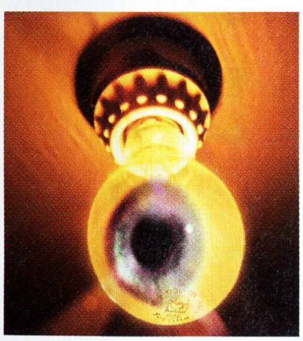
MICHAEL SIMPSON

Chemicals make sensitive bacteria shine.

Researchers have genetically engineered a bacterium that can sniff out toxic chemicals at parts-per-billion concentrations. That doesn't sound like a lot, but it's the level at which human health effects are often first seen, say the system's developers, Michael Simpson of Oak Ridge National Laboratory and Gary Sayler of the University of Tennessee. Unlike other bacterial sensors, which require large and expensive instrumentation, this device is small and potentially inexpensive. Bacteria engineered to detect specific chemicals are deposited on chips less than two millimeters long. Upon exposure to the target chemical, the bacteria glow with an intensity proportional to the concentration of the chemical. The sensors can detect environmental pollutants such as compounds that mimic estrogen, residue from jet fuel in ground water, and chemicals that indicate food spoilage. The researchers have built a working prototype and hope an upcoming alliance with Perkin-Elmer will bring the device to market within three years.

Anybody There?

You're sitting at your desk in deep thought, fingers poised above the keyboard to record your next flash of brilliance. In mid-thought, the lights go out, forcing you to wave goofily at the energy-saving occupancy sensor on the wall that has mistaken your lack of motion for absence. To avoid this scenario, some office workers override the sensors to keep the lights blazing all the time—not exactly in the spirit of conservation.

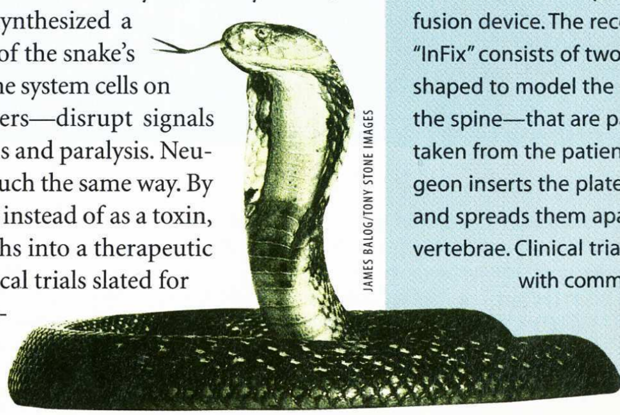


VITO ALUIA

A smart sensor, designed by Narendra Bansal and colleagues at the Indian Institute of Technology in Delhi, could minimize this annoyance. The device studies activity patterns of people in a room throughout the day and week. During busy hours the sensor will require longer periods of apparent inactivity before flicking off the lights. Bansal has begun preliminary discussions with companies that might commercialize the sensors.

Saved by the Snake?

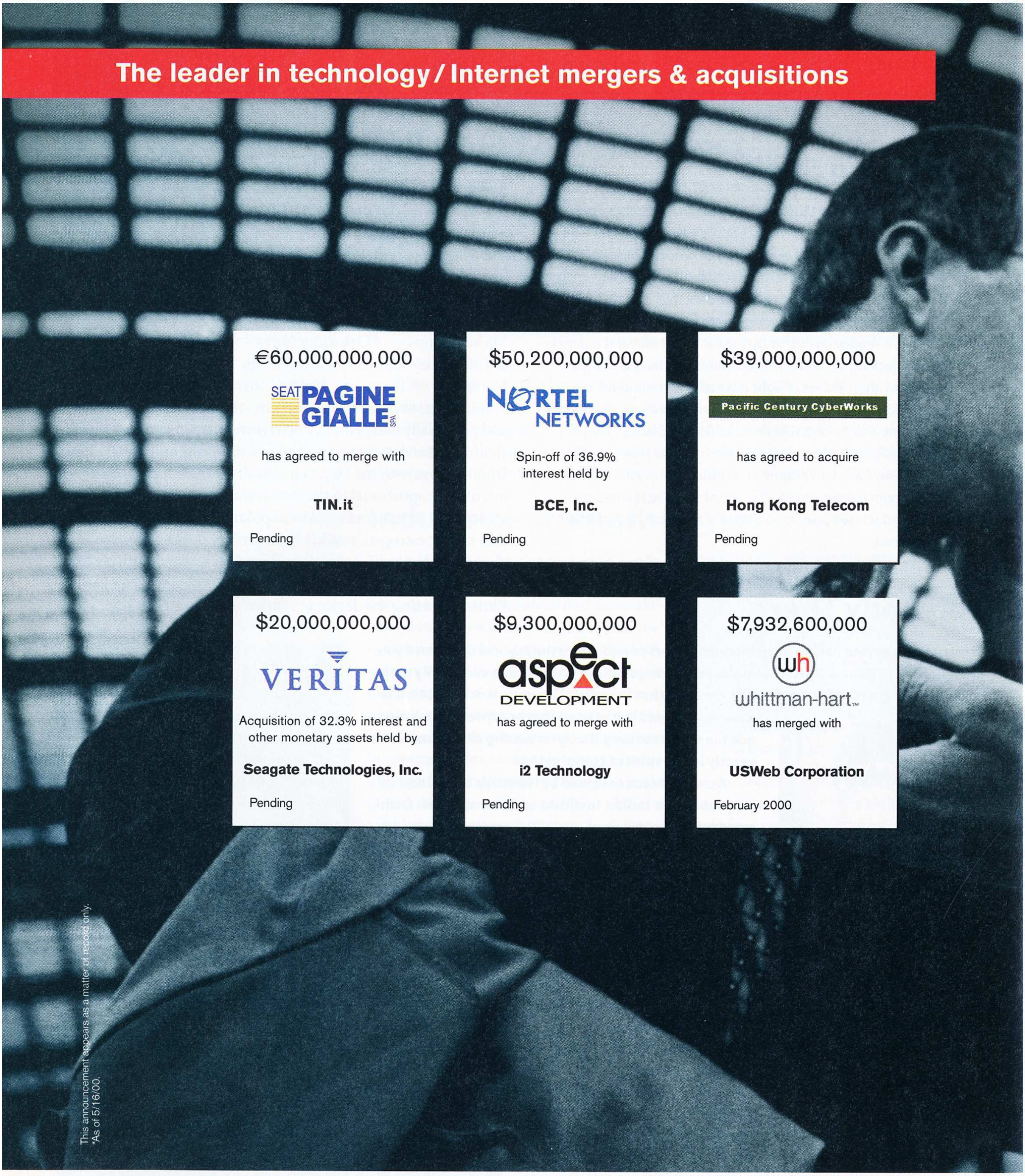
Cobra venom is deadly stuff (about 20,000 fatalities a year globally), but it may also be a healer. A new drug derived from the venom has shown promise against multiple sclerosis (MS) and sister diseases affecting the nervous and immune systems. PhyloMed, a pharmaceutical company in Plantation, Fla., has synthesized a harmless peptide (small protein) from constituents of the snake's venom, that acts as a kind of decoy. Attacks by immune system cells on myelin—the fatty material surrounding nerve fibers—disrupt signals between nerve cells to create characteristic MS lesions and paralysis. Neurotoxins from cobra venom paralyze nerve cells in much the same way. By binding to nerve cell receptors as a modified peptide instead of as a toxin, the venom-derived drug, called Immunokine, morphs into a therapeutic agent that can reverse MS's debilitating effects. Clinical trials slated for this summer will target MS and adrenomyeloneuropathy (a progressive genetic disorder of the adrenal gland that results in nervous system deterioration).



JAMES BALOG/TONY STONE IMAGES

Backup Plan

A new way to repair bad backs could offer relief to tens of thousands of people. Each year in the United States, some 75,000 people undergo surgery to relieve back pain. One common procedure fuses compressed vertebrae, limiting the movement that pinches surrounding nerves and causes discomfort. Such fusion now requires the surgeon to screw a hollow, porous cylinder into the space between compressed vertebrae. But this twisting action strips the bone of the tough coating that provides strength. Now Spinal Concepts—a four-year-old venture-backed company in Austin, Texas—has developed a less invasive fusion device. The recently patented "InFix" consists of two porous plates—shaped to model the natural curve of the spine—that are packed with bone taken from the patient's hip. The surgeon inserts the plates into the spine and spreads them apart, fusing the vertebrae. Clinical trials are under way, with commercial availability expected by 2002.



CREDIT SUISSE | FIRST BOSTON

Technology Group

$4,300,000,000
SIARA SYSTEMS
has merged with
Redback Networks
March 2000

$4,283,000,000
SILKNET
has agreed to merge with
Kana Communications
April 2000

$3,250,000,000
NORTEL NETWORKS
has acquired
Qtera
January 2000

$3,250,000,000
Xros
has agreed to be acquired by
Nortel Networks
Pending

$3,200,000,000
E.PIPHANY
has agreed to acquire
Octane Software
Pending

$2,430,000,000
EarthLink
has merged with
MindSpring
February 2000

$2,100,000,000
NORTEL NETWORKS
has acquired
Clarify, Inc.
March 2000

$2,000,000,000
COMMERCE ONE
has entered into a strategic alliance with
General Motors
Pending

$1,700,000,000
C-CUBE
has merged DiviCom with
Harmonic, Inc.
May 2000

$1,400,000,000
NETIQ
has merged with
Mission Critical Software
May 2000

$1,100,000,000
VA LINUX SYSTEMS
has agreed to acquire
Andover.net
Pending

$990,000,000
CONEXANT
has acquired
Maker Communications
March 2000

$905,000,000
Efficient Networks, Inc.
has agreed to acquire
NetScreen Technologies, Inc.
Pending

$890,000,000
PMC
has acquired
AANetcom
March 2000

$850,000,000
phone.com
has acquired
OneBox.com
April 2000

$674,000,000
CYGNUS
has been acquired by
Red Hat, Inc.
January 2000

$561,000,000
Liberate
has agreed to acquire
MoreCom, Inc.
Pending

$490,000,000
phone.com
has acquired
Paragon Software
March 2000

$471,000,000
WindRiver
has acquired
Integrated Systems
February 2000

$470,000,000
enCommerce
has agreed to merge with
Entrust Technologies
Pending

$444,000,000
DBT ONLINE, Inc.
has agreed to acquire
Choice Point
Pending

$415,000,000
PMC
has acquired
Extreme Packet Devices
April 2000

$409,000,000
E.PIPHANY
has acquired
RightPoint
January 2000

$333,000,000
Netcentives
Rewarding Relationships
has acquired
Post Communications
April 2000

$213,750,000
PHILSAR SEMICONDUCTOR
has agreed to be acquired by
Conexant
Pending

$175,800,000
TUMBLEWEED COMMUNICATIONS
has acquired
WorldTalk
February 2000

€150,000,000
BOSCH
has sold Bosch Telecom Public Network Product Group to
Marconi
January 2000

$116,000,000
Anteon corporation
has agreed to acquire
Analysis & Technology, Inc.
Pending

$100,000,000
FAIRCHILD SEMICONDUCTOR
has agreed to merge with
QT Optoelectronics
Pending

$100,000,000
Marconi
has acquired the SDH/WDM Transport Business of
Nokia
January 2000

$24,800,000
Netcentives
Rewarding Relationships
has acquired
Universal Value Network
March 2000

Undisclosed
BOSCH
has sold Bosch Private Networks Division to
Kohlberg, Kravis & Roberts
January 2000

Undisclosed
DeltaKabel
has been acquired by
Lucent
April 2000

Undisclosed
SCHUMANN
has been acquired by
Systor
January 2000

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Internationalize the Internet!

THERE ARE 1 BILLION OF US. WE SHOULD BUILD our own Internet and lock out the English-language Internet! That was the undercurrent theme I encountered last March at a Taipei conference titled "A Chinese Language Based Internet Economy."

There is ample justification for the Chinese, and other non-English speakers, to be frustrated over their inability to access the Internet. They want to participate and benefit from this huge socioeconomic revolution. But the overwhelming majority do not understand English, or the other mostly European languages of the Internet, and they feel left out. For the Chinese people, the problem is worse because of their many ideograms, which make keyboard use nearly impossible. The Chinese, like all the rest of us, will have to live in a world of many human languages. What might they and we do about it?

The Chinese should begin by forgetting the absurd idea of a linguistically private Internet. In a Chinese Internet, who would buy the millions of computers, cell phones, TV sets and other manufactured goods now sold by the Chinese to Western companies? With 80 percent of the Internet's economic activity business-to-business, and with economic globalization expanding, such a move would spell economic suicide. Instead, the Chinese, the other non-English speakers around the world, and the English speakers, should shape the Internet into a truly international medium that is equally useful to all its participants. This is not a utopia! Before we show how it can be achieved, let's take a peek at the potential benefits.

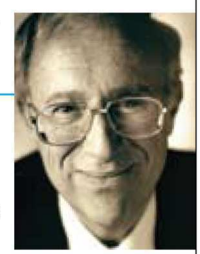
The best avenue toward internationalization is the ancient practice of translation—with an important twist.

Take information access. There is a huge amount of educational, cultural, governmental and other information within China that will benefit the Chinese, in the same way the current mass of information on the Web benefits English speakers. Information access between China and the West would be just as beneficial in both directions, for example to exchange information about Chinese and Western medicines, culture, tourism and trade.

Next, take Internet-mediated human-to-human transactions, which include the purchase and free exchange of goods and office work. The Chinese would profit from sharing among themselves information on recreation, trade, health, government, education and a myriad of other services. They would also benefit from a brisk international brokerage and trade activity with the rest of the world. And, who knows, the increased proximity among them from these activities might even help heal China's political split.

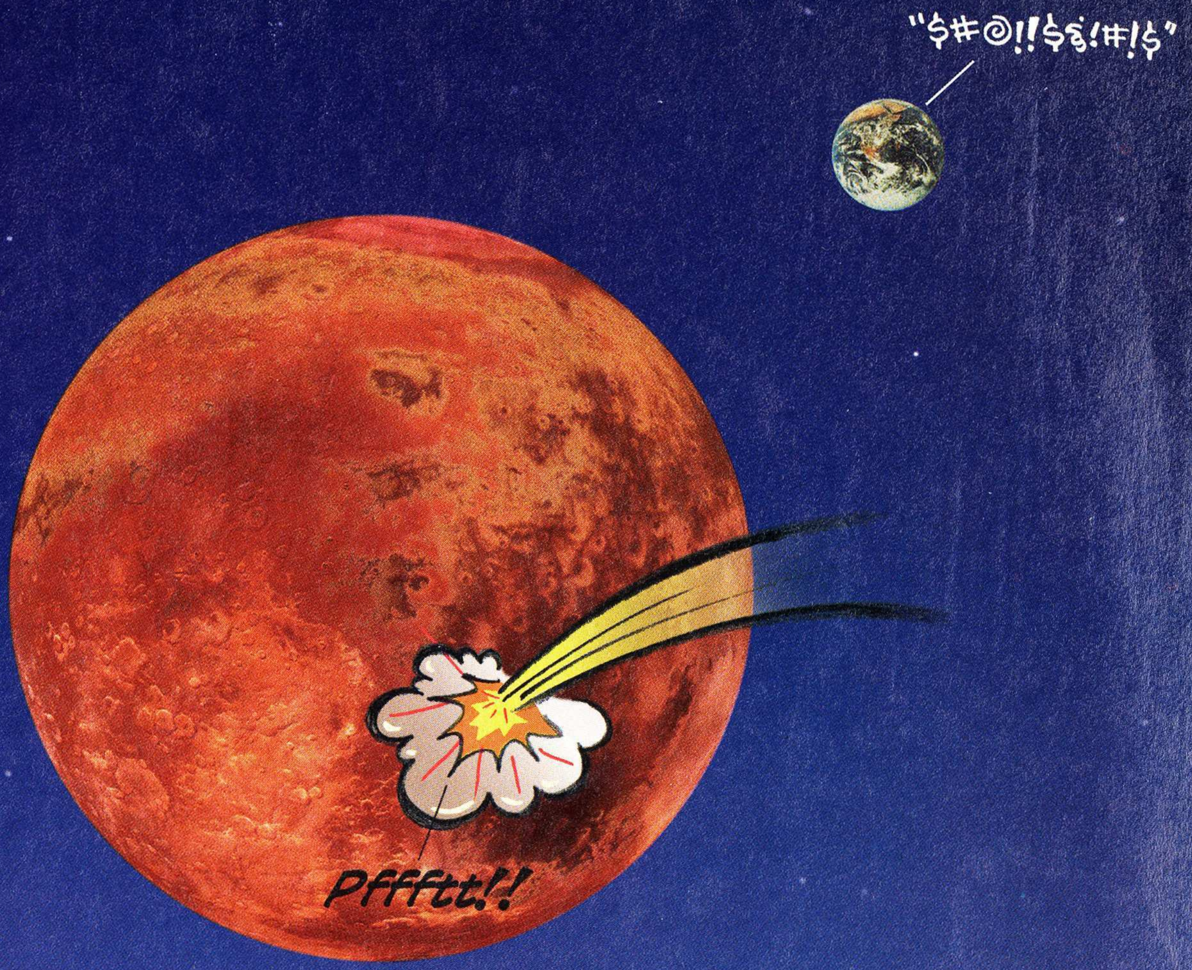
But let's not get carried away: Not all forthcoming technologies will be equally helpful to each economy. Automation will be useless within China and India, where labor is plentiful and inexpensive. And there is the problem of the poor around the world, whose participation in the Internet involves more formidable barriers than language.

How do we get to a truly international Internet? Through a combination of modern technology and ancient human practices. On the technology side, commercial speech understanding systems are finally emerging that can recognize more than 90 percent of the words spoken by their users. The Chinese could use this technology to speak to their machines without having to resort to ideograms. Although Chinese keyboards are far more complex than English keyboards, experimental speech understanding systems at the MIT Lab for Computer Science for Mandarin Chinese are no more complex than those for English. Unlike typing, speech understanding by machine seems equally practicable for both languages.



Speech technology could also help people who cannot read or write, but who could still have productive exchanges on the Internet using their native speech. However, the most promising avenue to internationalization will be the ancient human practice of translation, but with an important twist we'll call "total translation." By this, I mean not only a conversion of a Web site's sentences from one language to another, but also a "translation" of the culture and mindset of the site to the culture and mindset of its new audience—a difficult yet essential task.

Here's how this approach would work: People with superior knowledge of at least two languages would form a new breed of dot-coms that would offer total translation services to organizations in each of their linguistic territories. A Chinese company, specializing in Chinese and English, would sell its services to Western companies anxious to do business in China, and to Chinese organizations seeking Western visibility. The translator companies would thrive, because the economic motives toward universal visibility and reach are powerful. So much so that they could overflow beyond the commercial sector to help the spread of noncommercial multilingual sites. After a long time, this process would cause the distribution of languages on the Net to approach the distribution of languages around the world. Chinese would then dominate the Internet, making the absurd idea of a Chinese-language based Internet Economy a reality…that was obvious all along! ◊



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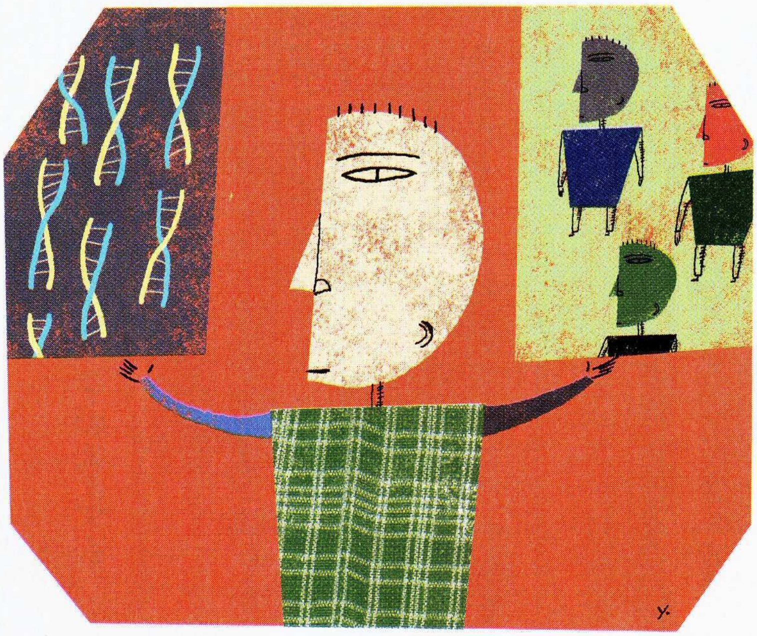


JAMES YANG

BIOTECHNOLOGY

Medical Records, Inc.

Firm set to mine Framingham Heart Study

THE UNITED STATES' MOST FAMOUS epidemiological study, the Framingham Heart Study, is about to take a medically promising step that could help in the effort to discover genes responsible for common diseases. But the move is also likely to raise questions about the commercial exploitation of patients' medical records.

Since the Framingham study began in 1948, some 10,000 residents of Framingham, Mass., have been poked, prodded and measured every two years in a massive effort to uncover risk factors for heart disease. The study has been extraordinarily successful, turning up, among other things, the link between cholesterol and clogged arteries. Now, officials at Boston University, which administers the study on behalf of the National Heart, Lung, and Blood Institute, have formed a company to mine the data for genes that contribute to diseases such as dementia, arthritis and the onset of deafness in adults.

Framingham Genomic Medicine plans to spend millions over the next several years to organize the information and begin large-scale DNA testing. "The amount of data ready to be culled out of this study is limitless," says chief scientific officer Fred Ledley.

The demand for so-called "phenotype" data (measurements of an individual's actual physical characteristics) from well-studied populations like Framingham is rising dramatically thanks to rapid advances in genetic technology. "Genetic analysis can be done with an arbitrarily great degree of precision. But you are limited by patient data," says Ledley. "This is the missing link."

In fact, genomic researchers expect they will eventually need medical data on hundreds of thousands, even millions, of people. For that reason, some European governments with centralized health care systems are now casting hungry eyes on their citizenry's medical records. The U.K. Medical Research Council, for instance, is planning a massive study involving more than 500,000 volunteers, and scientists have lobbied the U.K.'s National Health Service to create a genetic database encompassing the entire British population. Similar national databases are under consideration in Italy and Estonia.

So far, however, private companies have taken the lead in creating phenotype databases—a move that's proved both lucrative and controversial. In Iceland, Reykjavik-based deCode Genetics, which got government approval to create a database based on the medical records of that nation's 275,000 citizens, has been accused of violating patient privacy and plundering Iceland's genetic heritage. Despite the criticism, the company has signed a research alliance worth up to $200 million with Hoffman-La Roche, which hopes to use the data as a starting point for new medicines.

The question of who should benefit from a patient's medical records is also at issue in the Framingham study. "We are trying to be very open and proactive with the Framingham population, to get their buy-in and support for what we are doing," says Art Klausner, a partner with Domain Associates in Princeton, N.J., part of a financial consortium that's planning to invest $22 million in Framingham Genomic Medicine. The company plans to donate some of its profits to the Framingham community.

While experts in biomedical ethics say that's a good start, exploiting phenotype databases for commercial purposes remains problematic. For instance, do the consent forms patients sign to participate in such studies include adequate disclosures of how their DNA and tissues will be used in the future? "Privacy drives the concern about these databases. People are fearful that information about genetics could be used against them," says Arthur Caplan, director of the University of Pennsylvania Center for Bioethics. Entire ethnic groups may also be at risk, since genetic research could lead to findings, such as vulnerability to a specific disease, that could stigmatize them. "The very things that make a population good to study also make it tricky," says Caplan.

—Antonio Regalado

TELECOMMUNICATIONS

Light Signals Direct

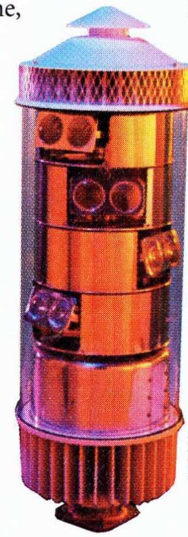
Local optical networks skip the fibers

THE TELECOMMUNICATIONS BUSINESS has always involved some risks. But now two of telecom's largest companies are investing in thin air.

Lucent Technologies is spending $450 million on a joint venture with Seattle-based TeraBeam Networks to build communications systems that will transmit light directly between buildings, skipping optical fibers altogether. Not to be outdone, rival Nortel Networks is developing a line of similar equipment with San Diego-based AirFiber. The goal of both ventures: shoot laser beams between medium and large businesses in downtown areas or office parks, providing vastly more voice and data capacity than ordinary phone lines without the expense and delay of laying fiber-optic cable.

The explosion in the Internet means that businesses have an ever-growing appetite for bandwidth. Fiber optics, which can carry data at gigabit speeds, can readily provide that capacity, but less than 5 percent of downtown office buildings are currently "wired" with fiber. New installations take time, and construction costs can be staggering. Ever try digging up the sidewalk in midtown Manhattan?

Don't expect the new technology to replace fiber-optic networks. But for businesses needing from 10 to several hundred megabits per second of bandwidth at one-tenth the cost of installing fibers, it could be a boon. "We don't consider it revolutionary. But it's a useful concept," says Jeff Montgomery, chairman of ElectroniCast, a telecom consulting firm in San Mateo, Calif.


AIRFIBER

AirFiber's optical nodes are positioned on top of a building.

Shooting laser beams through the air between buildings is not a new idea. In fact, laser communication through open air was demonstrated in the early 1960s. But the technique lost out to fiber optics; in earlier systems anything from bad weather to passing birds could interrupt the pencil-thin beams and destroy the line of communication.

The new systems are designed to be more reliable—pigeon-proof. Both TeraBeam and AirFiber use redundant beams, each spread over a larger area, so interruption would require almost complete blockages of multiple large beams. AirFiber arranges an interconnected mesh of rooftop transmitters and receivers, spaced 200 to 500 meters apart, depending on clarity of the local atmosphere; at least one node in the mesh connects to a fiber-optic backbone. Each transmitter aims beams of light at three or four receivers, building up a redundant mesh with multiple interconnections. TeraBeam puts a base transmitter in a strategic window in a building served by a fiber-optic network.

The companies have demonstration systems up and running—TeraBeam in Seattle, and AirFiber in Madrid, Tokyo and Dallas. **—Jeff Hecht**

NANOTECHNOLOGY

Tethered to Silicon

Silicon is at the heart of today's computer microchips. Making faster and cheaper computers means carving vanishingly small transistors into silicon chips—a task that is becoming increasingly difficult and expensive. One potential solution is to use individual organic molecules, which are orders of magnitude smaller than today's transistors, on a silicon surface to do electronic switching and storage.

Making such silicon-organic hybrids, however, poses a very, very small problem—how do you put the molecules exactly where you want them? Electrical engineers at the University of Illinois at Urbana-Champaign have now found a way to attach individual organic molecules to silicon with atomic precision, using the tip of a scanning tunneling microscope.

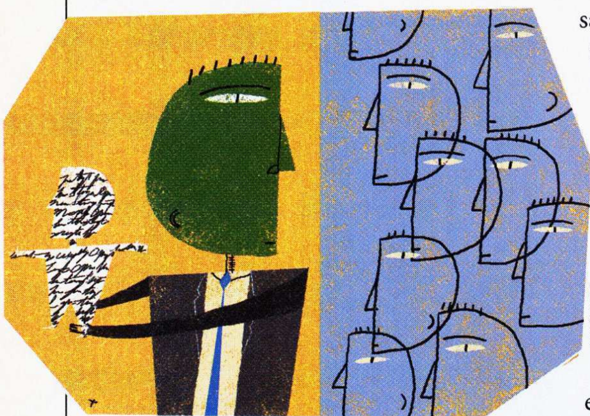
First the researchers deposit a layer of hydrogen, one atom thick, on the silicon surface; then they use the microscope's tip to pluck off individual hydrogen atoms in a desired pattern. The result, says Joe Lyding, professor of electrical and computer engineering at Illinois, is "a dangling silicon bond [where the hydrogen atom was] that is very reactive." Various organic molecules can then be sprayed on the surface, where they will attach themselves only to the "dangling bonds."

So far, Lyding and his graduate student Mark Hersam have fabricated simple patterns—columns and a V-shape—by spraying on molecules such as buckyballs (a soccerball-shaped 60-carbon molecule that many researchers believe has promise in electronics). Lyding envisions that the technique could eventually lead to hybrid silicon chips with ultrafast molecular switching and storage arrays. But, he adds: "In a sense this is uncharted territory. Nobody has placed individual molecules into atomically precise arrays on silicon before." **—David Rotman**

LEGISLATION

Canada Gets Private

Federal law aims to protect personal information


JAMES YANG

SEND YOUR E-MAIL ADDRESS TO AN online florist, and months later you may well get a marketing plug using—you guessed it—that same e-mail address. That's a troubling development for those concerned about personal information winding up in corporate databases. Canada has taken these concerns seriously, passing legislation to better protect the privacy rights of its citizens. The new federal law, the Personal Information Protection and Electronic Documents Act, mandates rules businesses must follow in collecting and processing personal information; it requires, among other things, that companies obtain an individual's consent for specific uses of data.

Much of the attention to privacy issues over the past year has focused on the Internet, and the opportunity the Net affords business and government to collect extensive information about citizens. But the Canadian law applies to all data collection activities. That means banks and insurance companies collecting data in traditional ways, as well as the latest e-commerce trading site.

"In order for Canada to become a leader in the knowledge-based economy and in electronic commerce, consumers and businesses must be comfortable with the new technologies and with the impact that these technologies will have on their lives," said John Cannis, MP from Scarborough Centre, speaking shortly before the legislation passed the Canadian Parliament this spring. Cannis said the law creates a "level playing field" for all Canadian companies. "The direct marketing industry, information technology companies, telecommunications companies and banks all realize that we need a clear federal legislative privacy framework in Canada. And they recognize that flexible, but effective, legislation will help customers accept electronic ways of doing business and be less expensive for them than self-regulation alone."

The Canadian privacy law was a long time coming, says Ann Cavoukian, Information and Privacy Commissioner for the province of Ontario. The principles incorporated into the legislation date back to 1995, when the Canadian Standards Association passed a voluntary privacy code; it called for companies to explain why information is being collected in the first place, obtain consent from the consumers, ensure accuracy of the collected data and provide safeguards against accidental disclosure.

The legislation essentially makes the voluntary code a law. "For companies that haven't been doing anything," says Cavoukian, "it will represent a fair amount of work at the beginning. For the first time, they will have to think about what is the primary purpose of the data collection, and then obtain the consent of their customers to use the information for other purposes."

Cavoukian argues that it's time for the United States to consider similar legislation. Currently, U.S. policy relies almost exclusively on self-regulation to protect consumer privacy. That only works, she says, if there is a "demonstrated commitment on the part of the businesses" to protect privacy. Looking over her country's southern border, she says drily, "I haven't seen this."

—Simson L. Garfinkel

AEROSPACE

Space Plane Grounded

Far from being ready for space, NASA's billion-dollar space plane, a critical transitional craft in replacing the Space Shuttle, is in deep trouble. The maiden test flights of the X-33 hypersonic plane were scheduled for the middle of this year. But NASA now says the prototype will not fly until at least the end of 2001.


NASA

The wedge-shaped X-33 is a prototype of a vehicle NASA hopes will replace the Space Shuttle.

Indeed, if the critics have their way, the X-33 may never leave the ground. At congressional hearings in April, House space subcommittee chairman Dana Rohrabacher criticized NASA's strategy for replacing the Space Shuttle. "By resisting the philosophy of build a little, test a little, NASA had put all of our cheap-access-to-space eggs in one fragile technology basket."

The X-33 has been an ambitious—and controversial—project from the start. The plane, being built by a NASA-Lockheed Martin partnership, is meant to demonstrate the feasibility of "single-stage-to-orbit" (SSTO) technology. If the X-33 proves the credibility of the SSTO strategy, the technology could be used in a privately funded spaceship, Venture Star, to replace the Space Shuttle.

At stake is more than just a suitable replacement for the Space Shuttle. The X-33 will be NASA's first new space-related flight test program in two decades. And many observers are watching to see whether the sometimes beleaguered space agency has any technology magic left.

—James Oberg

BIOMEDICINE

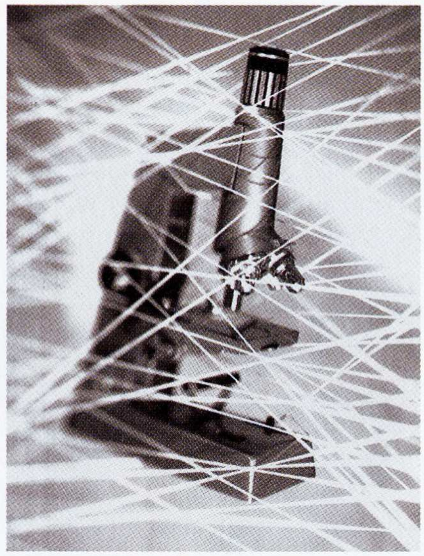
Cures on Hold

Scarcity of stem cells blocks biomedical progress

NEARLY TWO YEARS AFTER THE ISOlation of human embryonic stem cells promised to change the face of medical research, progress is still on hold due to scientists' limited access to the cells. Private companies are restricting use of their supplies, and government initiatives to provide the cells to academics remain stalled by abortion politics.

ES cells, believed to be capable of turning into any kind of tissue, are derived from human embryos. A law prohibiting federally funded researchers from performing embryo research has left most academic scientists effectively barred from working with ES cells, although the National Institutes of Health has recommended that researchers be able to use existing ES cell lines. A bill pending in the U.S. Senate would allow researchers to derive new ones as well. Critics of the research are opposing both measures.

This game of political football has left the research community in a bind, with few good options for getting the cells. Although the University of Wisconsin (where ES cells were isolated in 1998) has created an institute called WiCell to distribute ES cells, scientists that come knocking are being asked to sign an agreement with "unacceptable and ridiculous" strings attached, says Harvard University embryologist Doug Melton. Not only does WiCell demand commercial rights to any discoveries made, but also reserves the right to terminate research at any time with 90 days' notice.



STEPHEN SHEFFIELD

"The agreement holds the Sword of Damocles over your research," says George Daley, a biologist at MIT's Whitehead Institute. Unable to find an acceptable source of ES cells in the United States, both Melton and Daley have turned to a university group in Israel that's begun distributing the cells.

But because such trafficking still leaves most U.S. researchers out in the cold, several private medical charities are now gearing up to fund sources of ES cells that would be widely accessible. The Juvenile Diabetes Foundation has funded a researcher in the United Kingdom to derive stem cells. In a closed meeting in early April, leaders of the Howard Hughes Medical Institute (HHMI), the nation's largest biomedical not-for-profit, discussed the role the foundation should take in pushing ES cell research forward. According to people who attended the meeting, HHMI leaders discussed the idea of funding two or three centers to derive ES cells. These centers would be located in different parts of the country to ensure that one or more survive the wrath of pro-lifers in the state legislatures.

While biomedical researchers would welcome the entry of HHMI, many say it wouldn't be enough. Larry Goldstein, an HHMI-funded investigator at the University of California, San Diego who has been lobbying both Hughes and the government to let ES cell research progress, says privately funded research is moving forward, but only in the shadows, without proper public supervision. "Scientists with private funding are proceeding to the best of their ability. It's a mistake to think that if the government doesn't fund this work it will stop it in its tracks," says Goldstein. "There needs to be public input. To lose that voice would be wrong." **—Antonio Regalado**

METEOROLOGY

Taming Tornadoes

During an average year in the United States, some 800 tornadoes injure more than a thousand people. A California physicist believes it is possible to use blasts of microwave energy from a satellite to diffuse developing tornadoes before they can wreak their damage.

Bernard Eastlund, president of Eastlund Scientific Enterprises in San Diego, Calif., proposes using microwaves to heat the cool, rainy downdrafts that form a tornado. According to modeling by Eastlund on supercomputers at the University of Oklahoma's Center for Analysis and Prediction of Storms, about 100 million watts of energy added to the descending air column could disrupt a downdraft that otherwise might spawn a tornado.

Federal Emergency Management Agency (FEMA) physicist Paul Bryant, an expert on tornadoes, thinks Eastlund's idea is practical. "He's got a good concept and has demonstrated in computer models that you can arrest a tornado," Bryant says. Bryant, who is FEMA's adviser to NASA on its efforts to mitigate natural disasters, says the International Space Station would be an ideal vehicle for an initial test that would involve diffusing developing waterspouts over remote sections of ocean.

Not everyone thinks that's a great idea. Dan McCarthy, a tornado expert at the National Oceanic and Atmospheric Administration's Storm Prediction Center in Norman, Okla., cautions that diffusing tornadoes might open a meteorological Pandora's box. "I'd be real careful in trying," McCarthy says. "You may set off another area of thunderstorms elsewhere." **—David Graham**

Hungry for Biotech

BIOENGINEERED CROPS WERE GROWN ON nearly 40 million hectares (100 million acres) in twelve countries last year—up from less than two million hectares when they were first introduced in 1996, making biotechnology the most rapidly adopted technology in the history of agriculture. But this phenomenal success has been a double-edged sword. Despite the certified safety of biotechnology-derived foods, opposition by environmental activists has undermined consumer confidence in the new gene technology. Food companies such as McDonald's and Frito-Lay are now asking their suppliers not to use bioengineered potatoes and corn. Many European countries are avoiding imports of bioengineered corn and soybeans entirely.

Meanwhile, the industry has responded with a public relations campaign of its own. The press releases and TV commercials extol potential benefits of biofoods, such as better nutrition and ameliorating the problem of world hunger. Although biotechnology clearly provides ammunition for improving food production, the fact is that right now there is little industry research on food staples of importance to the developing world. It's time for the industry to put its money—actually its patents—where its mouth is.

Life science companies say agricultural biotechnology will feed the world. So why are they standing in the way?

Nobody should expect Monsanto to end world hunger. That's like counting on Microsoft to wipe out illiteracy. The biotech industry has spent billions of dollars developing a powerful technology for redesigning crops to evade pests and diseases, and to improve food quality. But because investment dollars need to be recovered, the target of such research is on commercial crops in Western countries.

So where does that leave the developing world? Poor countries such as Ethiopia or Bangladesh don't have the funds or scientific talent needed to pursue biotech research on their own. Nevertheless, many public institutions are developing food crops with improved attributes such as "golden rice" rich in provitamin A, which can prevent blindness in children. In my own lab at Tuskegee University, we have created high protein sweet potatoes.

These new crops are designed to be distributed freely to farmers in the developing world. However, industry "ownership" of genes and technologies used to create such varieties represents a serious obstacle. Nearly every core technology used in crop biotechnology is the intellectual property of companies such as Dow, DuPont, Monsanto and Novartis. So if Vietnam or Liberia wants to distribute golden rice seeds to its farmers, it must first negotiate with various companies for the gene transfer, gene promoter and selectable marker technologies that were used in its development. Most poor countries simply do not have the financial resources or the scientific or legal acumen to wade through this complex patent maze. Thus, agricultural biotechnology cannot make inroads into developing nations without a "freedom to operate" license from the owners of these technologies—major life science corporations.

If companies really want to combat global poverty and hunger, they must make their technology available for use on select food crops such as rice, cassava and millet by developing countries on a royalty-free basis. Not only will this provide a tremendous boost to world food production, but it also makes good business sense. Acceptance of biotech food crops in the developing world would create market opportunities for commercial crops such as cotton, and would also give the industry a much-needed human face.

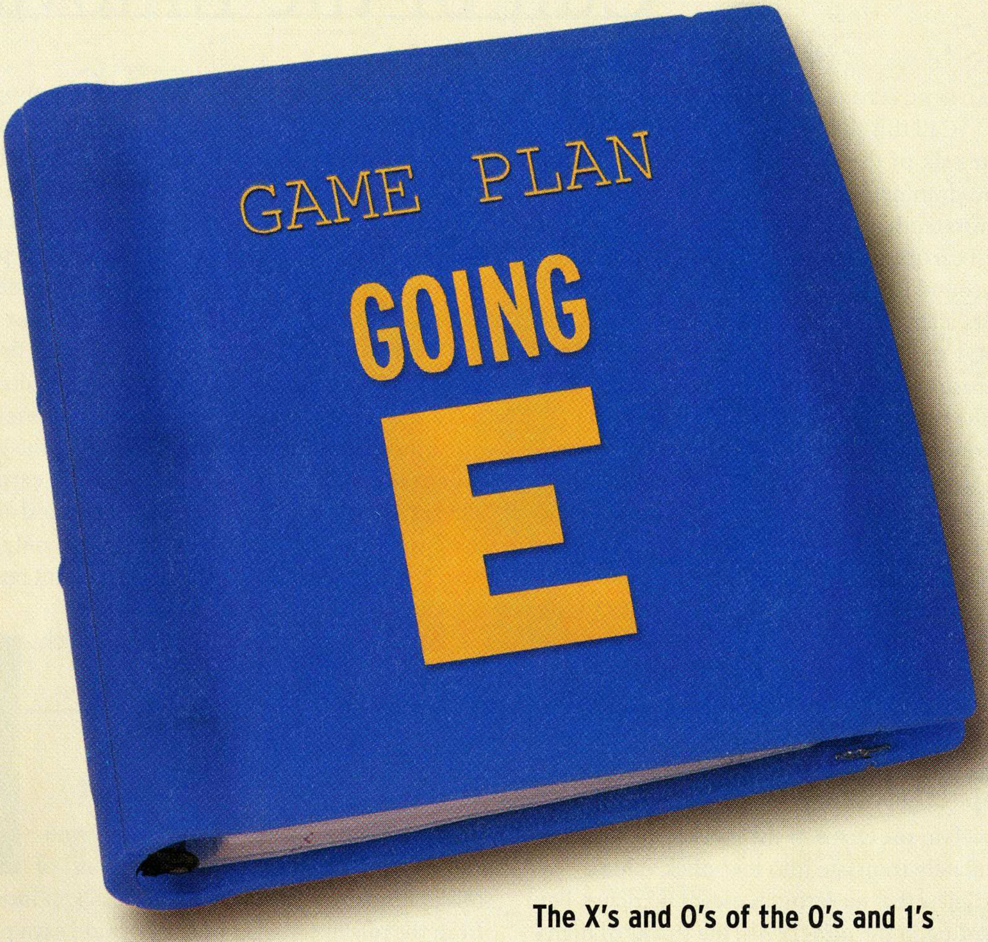
Would anyone oppose such a plan? Although there's much willingness among corporate scientists

to share technology, their lawyers cannot see beyond the issue of liability. Activists are also to blame. Their opposition to using new technologies in the Third World puts industry in a "damned if you do and damned if you don't" position.

Clearly, we need an independent middleman to take charge. Catherine Ives of the Agricultural Biotechnology Sustainability Project at Michigan State University believes that a new international agency should be set up to act as a "technology trust" that can assume responsibility for transferring biotechnology to developing countries. A central agency would not only help indemnify companies from liability suits, but would also help negotiate the labyrinth of patent laws and intellectual property claims.

The benefits of agricultural biotechnology are as real as the problems we face. In my native India, every third child is underweight due to malnutrition and 400 million people go to bed hungry every night. In a country where 70 percent of people are associated with farming, technological innovation in agriculture is critical not only to produce more food but also to improve living standards. It's time for the agricultural biotechnology industry to show a social conscience and clear the way for the harnessing of their newfound knowledge to combat global hunger and malnutrition. ◊

Professor C.S. Prakash teaches plant molecular genetics at Tuskegee University. He has recently received endorsements from 2,200 scientists across the world for his declaration in support of biotechnology in agriculture (www.agbioworld.org).



The X's and O's of the O's and 1's

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Cult of the Innovator

REAL INNOVATORS DON'T EARN PROFITS. Call this the "law of the pioneer." For all the talk of the riches to be gained by those who dominate new high-tech businesses, the stubborn truth is that trailblazers rarely get rich. Think of the first car-makers in the early 1900s. Or the first movie studios around the same time. Or the initial wave of airline companies after World War II. Or the postwar mainframe makers. Or the first PC suppliers in the 1970s. Or makers of database software in the 1980s. All these companies were in the right industry at the right time, yet precious few earned money.

This lesson is worth remembering in our time of turmoil in tech stocks. In the hoopla over the New Economy, many forget that pioneers pay a price, just as they did in the Old Economy. Successful innovators are like Moses, who led his people through the wilderness but never reached the Promised Land. Many innovators never get to the Promised Land either, which in the terms of the market means their low profits ultimately translate into low stock values.

People once knew that no earnings meant no riches. For four decades, ending in the mid-1990s, the stocks of high-tech companies traded at a lower price-to-profit ratio than stocks of conventional companies. This reflected the heightened risk of picking winners and losers in high-tech businesses. Many people think that the rise of the Net and e-commerce, with its dazzling potential, changed this. Not so. Rather the great success in the 1990s of the twin towers of the "pre-Net" economy, Microsoft and Intel, induced a collective amnesia in which innovation became synonymous with controlling a standard and achieving the power to exact exorbitant "rents" over essential goods. Under the sway of the Microsoft-Intel axis, the endgame of innovation came to be seen as market power rather than destabilizing markets by creating novel ways of meeting human needs.

While this sounds bad, it turns out that control over markets is the secret to earning steady profits. But such control need not flow automatically from innovation. In the case of Microsoft and Intel, market control was given to them by IBM, which effectively set all computing standards 20 years ago. Indeed, the greatest bursts of innovation for Intel and Microsoft came *after* they gained control of the chip and operating-system standards, not in their early days.

Innovators, then, have drawn the wrong conclusion from recent high-tech history. They seek to earn profits by winning control of markets through new products and services, when in fact innovators almost never gain market power because they are, well, too busy innovating. The experience of Netscape offers a classic example. The company pioneered the first commercial Net browser. It even won control of the standard. Yet its control was based on continued innovations, and when Netscape failed to keep that momentum, Microsoft's superior market power took precedence. Netscape never earned any money and ultimately ended up as a ward of America Online.

Or consider the dilemma of Amazon, the first truly successful electronic retailer. When Amazon realized it couldn't earn more than slim profits from selling books, it moved into other areas. But the cost of becoming the Wal-Mart of cyberspace is so great that Amazon won't earn profits for a long time, if ever. And since the bricks-and-mortar Wal-Mart wants to dominate the Net too, it is only a matter of time before Amazon sells out to the discount retailer—or to one of Wal-Mart's competitors.

Worship of innovators has distracted investors from realizing that most of them actually lose gobs of money.

Now you might say that this merely shows that Amazon, like Netscape, isn't innovative enough. But the predicament of these companies doesn't stem from lack of innovation but from the mistaken belief that they could earn profits in the first place. It's a business truism, or ought to be one, that an innovation must create a sustained competitive advantage or else it merely paves the way for rivals. This truism, by the way, explains the success of the Linux operating system. It became attractive as a standard precisely because no one was trying to use it as the basis for a profitable business. Because the Linux standard is free, the problem of wringing profits from this innovation never arises, which is one way of resolving the pioneer's dilemma.

The realization that innovators don't earn profits will cause some suffering on Wall Street. This isn't all bad. America has made a cult out of the entrepreneur and the innovator—so much so that even within the engineering community people feel they are somehow less if they can't blaze an original trail. This is unfortunate. Not everyone can, or should be, an innovator. As the computer pioneer Vannevar Bush pointed out in a short essay he wrote for this magazine, titled "The Builders," there are many important roles in the community of research and engineering. The role of innovator is only one, and it is rarer than most realize. This is good, since most innovators lose lots of money and, in the end, leave for others the hard work of turning a path into a highway. Those who come after and turn the innovation into a practical alternative are no less essential than the innovator—and a good deal better at posting profits. ◊

Perspective that helps power technology companies.

Photon Dynamics Inc.
$126,500,000
Follow-on Offering
Lead Manager
January 31, 2000

JDS Uniphase Corporation
$5,700,000,000
has acquired Optical Coating Laboratory, Inc.
M&A Advisor
February 1, 2000

Dobson Communications Corp.
$550,000,000
Initial Public Offering
Lead Manager
February 3, 2000

Therma-Wave, Inc.
$207,000,000
Initial Public Offering
Lead Manager
February 3, 2000

Autobytel.com, Inc.
$31,800,000
has agreed to acquire A.I.N. Corp. d/b/a CarSmart.com
M&A Advisor
February 16, 2000

Flextronics International
$507,400,000
Follow-on Offering
Lead Manager
February 24, 2000

Integrated Silicon Solution, Inc.
$96,772,500
Follow-on Offering
Lead Manager
February 24, 2000

American Superconductor Corp.
$218,750,000
Follow-on Offering
Lead Manager
March 1, 2000

Signio, Inc.
$1,400,000,000
has been acquired by VeriSign, Inc.
M&A Advisor
March 1, 2000

Exar Corp.
$276,000,000
Follow-on Offering
Lead Manager
March 7, 2000

Metalink Ltd.
$135,000,000
Follow-on Offering
Lead Manager
March 22, 2000

Anaren Microwave
$139,840,000
Follow-on Offering
Lead Manager
March 27, 2000

Vyyo, Inc.
$104,793,750
Initial Public Offering
Lead Manager
April 4, 2000

PCtel, Inc.
$127,900,000
Follow-on Offering
Lead Manager
April 11, 2000

Novellus Systems, Inc.
$500,000,000
Follow-on Offering
Lead (sole) Manager
April 18, 2000

Cree Inc.
$279,976,125
Follow-on Offering
Co-manager
January 14, 2000

Radware Ltd.
$129,375,000
Follow-on Offering
Co-manager
January 24, 2000

Sawtek, Inc.
$291,500,000
Follow-on Offering
Co-manager
January 24, 2000

Corning, Inc.
$2,263,056,250
Follow-on Offering
Co-manager
January 25, 2000

Interwave Communications International
$127,075,000
Initial Public Offering
Co-manager
January 28, 2000

L90, Inc.
$112,125,000
Initial Public Offering
Co-manager
January 28, 2000

SkillSoft Corp.
$49,910,000
Initial Public Offering
Co-manager
January 31, 2000

Telaxis Corp.
$78,200,000
Initial Public Offering
Co-manager
February 1, 2000

NBC Internet, Inc.
$374,325,000
Follow-on Offering
Co-manager
February 3, 2000

Sanmina Corporation
$563,450,000
Follow-on Offering
Co-manager
February 8, 2000

Semtech Corp.
$350,000,000
144A Convertible Subordinated Notes
Co-manager*
February 9, 2000

Imagex.com
$132,250,000
Follow-on Offering
Co-manager
February 11, 2000

Savvis Communications Corp.
$408,000,000
Initial Public Offering
Co-manager
February 14, 2000

Eloquent Inc.
$82,800,000
Initial Public Offering
Co-manager
February 17, 2000

TriQuint Semiconductor
$300,000,000
144A Convertible Subordinated Notes
Co-manager*
February 17, 2000

Celestica Inc.
$1,024,737,500
Follow-on Offering
Co-manager
March 1, 2000

UTStarcom Inc.
$207,000,000
Initial Public Offering
Co-manager
March 2, 2000

Clarus Corp.
$277,725,000
Follow-on Offering
Co-manager
March 7, 2000

HomeGrocer.com
$264,000,000
Initial Public Offering
Co-manager
March 9, 2000

International Rectifier Corp.
$397,750,000
Follow-on Offering
Co-manager
March 9, 2000

SCI Systems, Inc.
$500,000,000
Convertible Subordinated Notes
Co-manager
March 9, 2000

Uproar Inc.
$84,700,000
Initial Public Offering
Co-manager
March 17, 2000

Viasystems Group Inc.
$924,000,000
Initial Public Offering
Co-manager
March 23, 2000

ATMI Inc.
$126,000,000
Follow-on Offering
Co-manager
March 29, 2000

Saba Software, Inc.
$60,000,000
Initial Public Offering
Co-manager
April 6, 2000

Bookham Technology, Inc.
$306,500,000
Initial Public Offering
Co-manager
April 11, 2000

JDS Uniphase Corporation
$15,000,000,000
has agreed to acquire E-TEK Dynamics, Inc.
M&A Advisor
Pending

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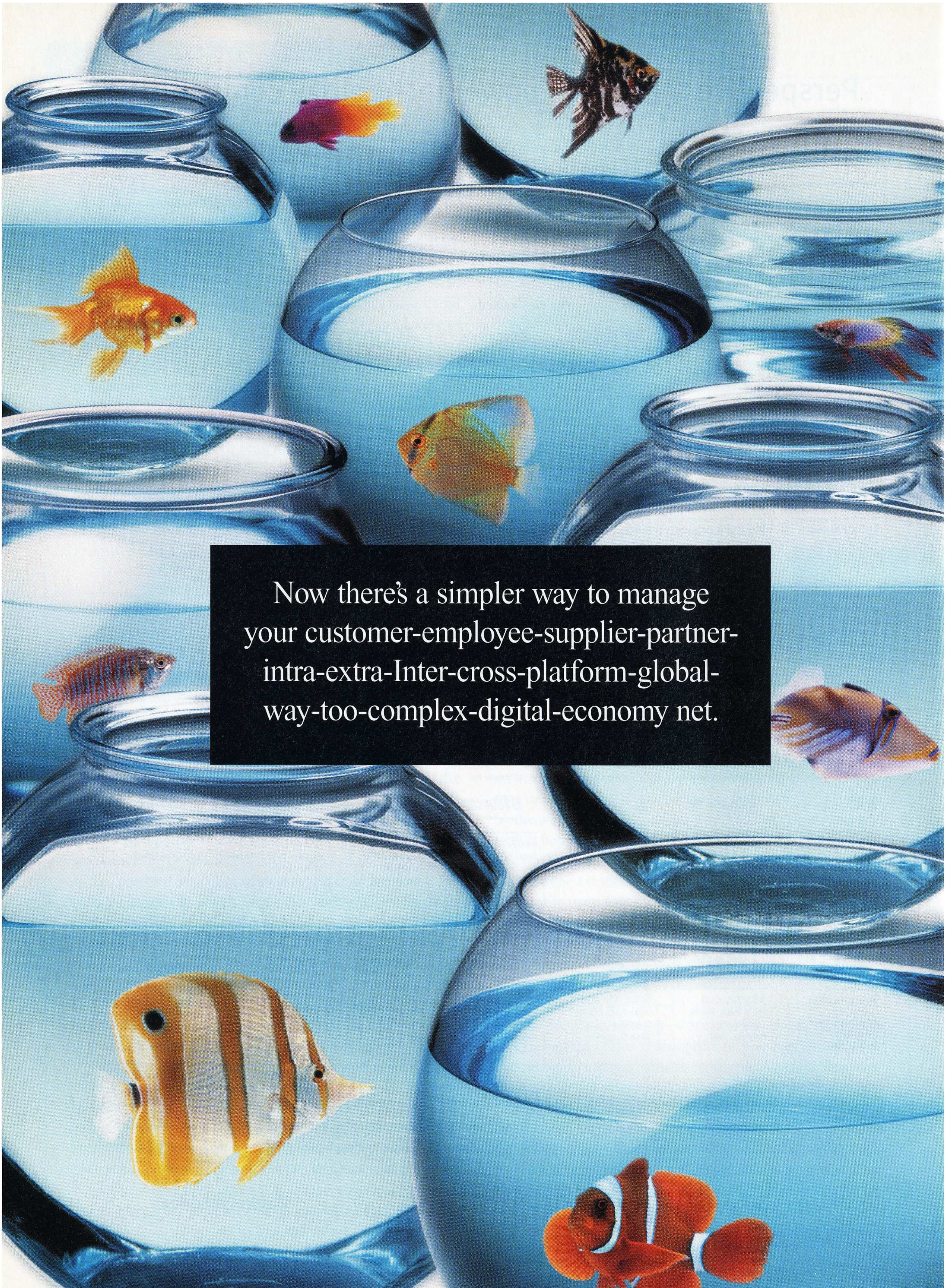

Now there's a simpler way to manage
your customer-employee-supplier-partner-
intra-extra-Inter-cross-platform-global-
way-too-complex-digital-economy net.

The Microphotonics REVOLUTION

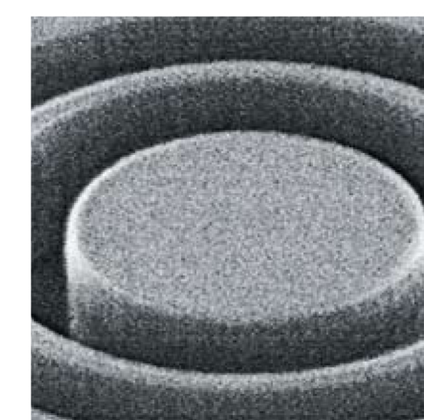
Get ready for optical switching in the telecommunications network backbone, then an all-optical Internet, and finally optical integrated circuits. The amount of data we can get almost anywhere will skyrocket. BY PETER FAIRLEY

At first glance, it's an unremarkable gadget. About the size of a nickel, the device is made using standard technology borrowed from inkjet printers that squirts tiny bubbles at the intersection of channels carved in a slice of glass. But this seemingly mundane piece of optical equipment performs one of today's most sought-after technology tricks. As light from an optical fiber shines onto it, the light is guided down one of the channels and, at the intersection, a bubble deflects the light beam, deftly rerouting it to just the right outgoing fiber. This "optical switch" is orders of magnitude smaller than anything now on the market and vastly outperforms existing devices, orchestrating 32 beams of light in less than one-hundredth of a second.

Not impressed? Consider that when Agilent Technologies, a recent spinoff of Hewlett-Packard, unveiled a prototype of the device at a technical meeting in Baltimore earlier this year, the company's stock soared 47 percent, adding $23 billion to its market value. Such investor exuberance is not limited to Agilent's version of the technology. Optical switches, which route information in the form of light, rather than converting it to electrons as most current switches do, have become one of the hottest items for those planning tomorrow's communications systems *(see sidebar)*. A week after Agilent's announcement, Nortel Networks spent $3.25 billion to buy a Silicon Valley startup called Xros that has a promising—but commercially untested—switching technology. And leading manufacturers of communications equipment, including Lucent Technologies and Corning, are making the development of their own optical switches a top R&D priority.

Unlike the seemingly indiscriminate passion for dot-com stocks, this exuberance isn't irrational. The reason for the excitement is that optical switches are a first step in the miniaturization of light-handling devices—an advance that promises to reshape global communications networks. They are a critical missing link in building a lightning-fast all-optical Internet capable of delivering bandwidth-hogging applications such as video-on-demand to users around the world. What's more, in the opinion of a number of researchers, the switches are a harbinger of tiny but complex optical devices that could change how data is transmitted in everything from communication systems to computers. "Microphotonics is the next revolutionary technology," says MIT materials scientist Lionel Kimerling, who leads a research effort to design optical devices and circuits on the same size-scale as computer chips.

The first critical application of photonic switches will be to eliminate costly electronic switching in the fiber-optic "backbones" (the communication superhighways that run from one major city to another). It's no surprise that the amount of traffic on these networks is exploding due to the Internet. The Yankee Group, a high-tech market research firm in Boston, estimates that new wireless technologies alone will connect a billion cell phones, laptops and personal organizers to the Internet worldwide over the next three years. Not only are more people and businesses going online, but the nature of Internet traffic is also rapidly changing with increased demand for video and music—applications with a tremendous appetite for bandwidth.



So far, communications systems have managed to keep up because the volume of phone calls, Web pages and videostreams that optical fibers can carry is doubling every nine months, thanks in large part to the ability to squeeze more wavelengths of light into each fiber *("Wavelength Division Multiplexing," TR March/April 1999)*. It is this remarkable growth in capacity that prevents your favorite MP3 recordings and webcasts from causing gridlock on the Internet.

The problem is that while optical fibers are carrying more and more information, when this speeding light reaches the networks' central hubs, it must still be converted into electrons and switched by bulky and expensive electronic switches and then converted back to light signals. Converting pulses of information from light into electrons worked fine when fiber optics carried only one signal over limited distances. But electronics have difficulty keeping up as the optical signals become more complex. In the current data maelstrom, the capacity of electronic switches is quickly being outpaced by that of the fiber-optic cables connecting the hubs. In the parlance of optical networking, this data jam waiting to happen is called the electronic bottleneck. "It's almost a law of nature that any kind of electronic box at the end of the fiber won't be able to deal with the kind of bandwidth coming out of it," says David Bishop, director of micromechanical research at Lucent Technologies' Bell Laboratories.

Enter the new breed of photonic switches—of which at least a dozen are on the way to market. These switches skip the step of converting light into electrons to switch the beams, and, unlike electronics, all-optical devices can deftly redirect even the most complex light streams. All the approaches being tried rely on shrinking the switch components. But after that, it's a technology free-for-all. Some, like Agilent, employ columns of glass called waveguides to shuttle the light to and from a switch. In the Agilent switch, bubbles deflect the light between crisscrossing waveguides; optical-fiber giant Corning is attempting to use liquid crystals—the same light-bending materials found in your cell phone and calculator readout—to redirect the beams. At Bell Labs, Bishop and his coworkers use arrays of tiny tilting micromirrors to manipulate hundreds of beams at the same time *(see graphic);* some 256 of these micromirrors fit on a few square centimeters of silicon.

These photonic switches will function in the network backbone much like the mechanical switches in a busy railroad yard. But that's only the start.

For those hoping to supply tomorrow's optical communications equipment, offering some version of these switches is critical to staying competitive. "You either have a technology in this space or you plan to be marginalized," says Bishop. "There's a huge amount of money at stake."

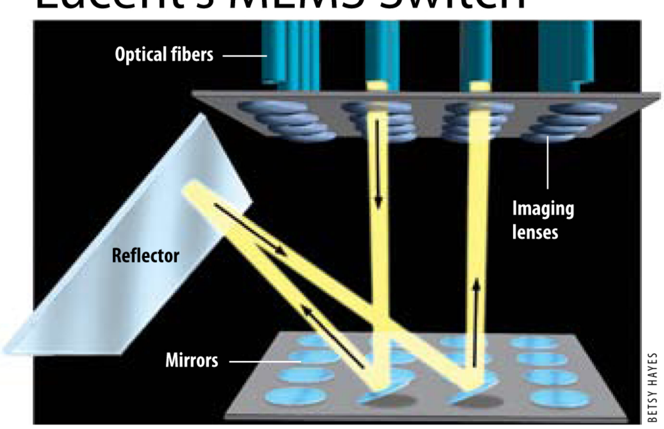
Indeed, network operators are already beginning to install the first generation of these photonic switches, using them much like the mechanical switches in a busy railroad terminal. One immediate advantage is that telecom providers will be able to reconfigure their networks on the fly rather than having to send out technicians to patch a maze of optical fibers. If a backhoe in Des Moines takes out MCI's Denver-to-Chicago line, tiny tilting mirrors may be all it takes to divert billions of data packets around the break. Operators will also be able to offer dedicated circuits linking a client's corporate headquarters to its manufacturing plants and customers. In the jargon of telecommunications it's called provisioning. "Today, it is a manually intensive process that takes months. The ability to do that at the software level is incredibly attractive," says Yankee Group optical networking analyst Alex Benik.

But that may only be the start. As photonic switches become even smaller, more functional and cheaper, many experts believe they could help bring the massive bandwidth of the network core closer to end users. "As this technology becomes more readily available, the high-speed pipes will extend further and further into the network," says David Andersen, R&D director for Agilent's optical networking division. "As that bandwidth becomes available the experience of the Internet will become richer and richer."

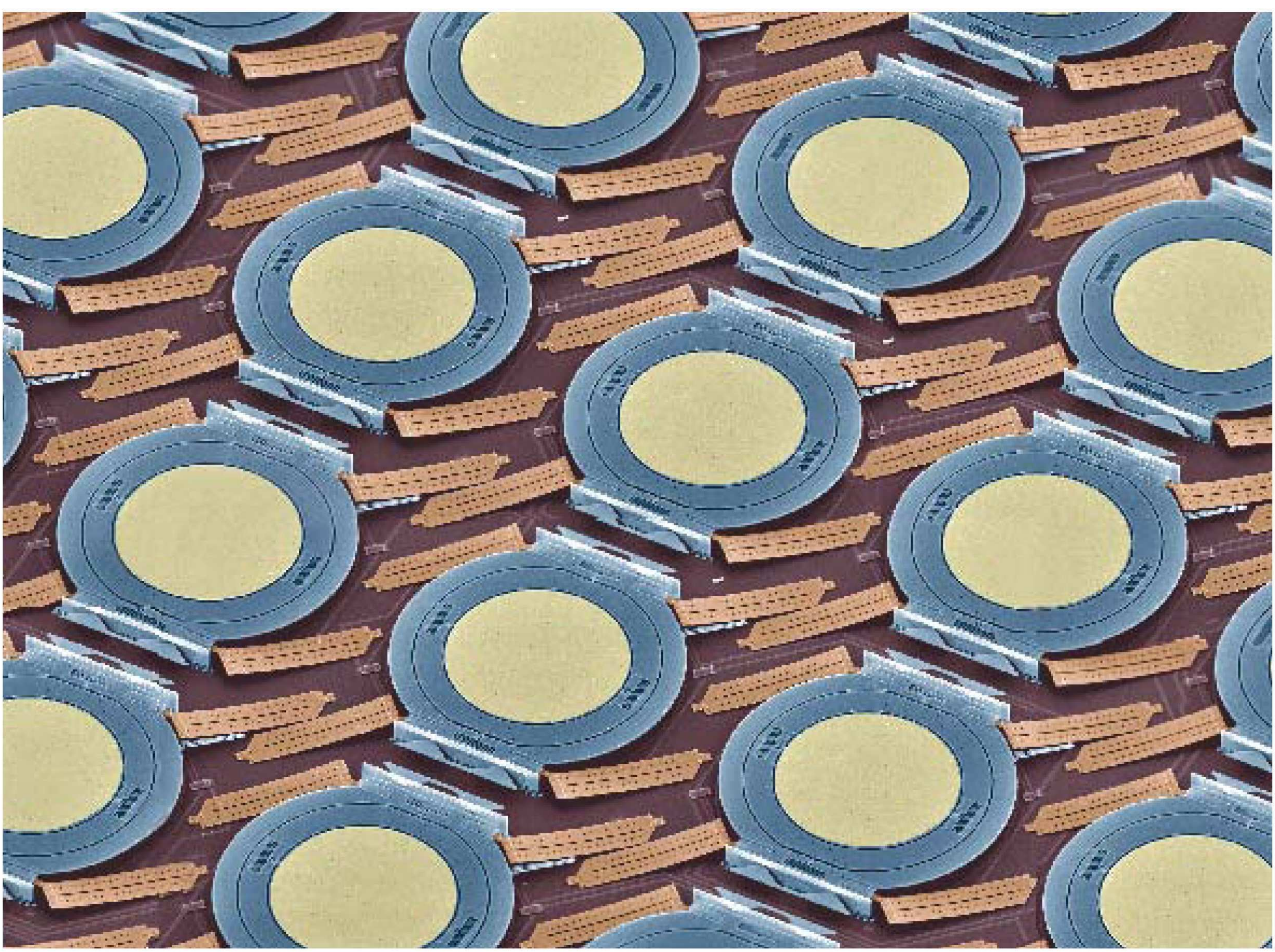
Smart Switches

Experts are quick to point out that even today's most impressive optical switches represent only an early step in the evolution of functional optical devices. In a world of advanced microelectronics, today's prototypes are still bulky—and they're dumb. Although they can switch light beams with ease, they can't read the messages carried in them. As a result, electronic devices must be used to control the photonic switches, telling them when and where to redirect the beams of light. That's acceptable if the goal is simply to reconfigure the main pathways of light at the network hubs. But that initial goal certainly will not satisfy the ambitions of telecom providers for long. They would like to extend the full power of optical switching all the way to the end users, creating a truly "all-optical Internet." And that means smarter

Lucent's MEMS Switch



Bouncing beams: In Lucent's switch, tiny mirrors are used to redirect incoming light to an outgoing fiber. The microelectromechanical system (MEMS) relies on electronics to control the tilt of the mirrors—and hence the route of the outgoing light.



Hall of mirrors: A close-up of the individual mirrors in Lucent's optical switch; each mirror is several hundred micrometers in diameter.

LUCENT TECHNOLOGIES

optical switching.

The Internet is built around packets—strings of data that find their destination by hopping between local and regional "nodes" where the mesh of transmission lines that form the Internet intersect. E-mail a snapshot and it will be chopped into hundreds or thousands of packets that travel separately from node to node. Each packet carries with it an Internet protocol, or IP, address that is read by electronic switches called routers at each node. Whereas the switches at the network backbone can blindly shift an immense number of packets in bulk, routers must ponder each packet. The IP address tells the routers where the packet is going; the routers then forward it to the next appropriate node. This process is repeated across the Net until the individual packets that make up the snapshot have arrived at their destination, where they are reassembled.

This forwarding arrangement is part of what makes the Internet resilient. If a node goes down or is temporarily swamped, neighboring routers simply divert the flow of packets around it. However, routers are straining to keep pace with the surging Internet traffic, just like their electronic cousins in the network backbone. Each channel of light in today's fastest fiber-optic cables transmits thousands of packets every second, with additional channels being squeezed in all the time. While electronic routers have managed to keep up with converting the optical signal to electrons and reading the IP address on each packet, they are now being pushed to their limits.

Herein lies the next big job for photonic switches. In tomorrow's all-optical Internet, operating at speeds unimaginable with electronics and delivering that speed to your home PC, photonic switches must be smart enough to serve as routers by recognizing the packets of information and determining where they should go. In other words, the devices must have the speed of optics and the intelligence of microelectronics. And that will happen, say those in the field. "The future of networking is going to be optical IP switching," says Gary Bjorklund, chief technology officer with Miami-based Nanovation Technologies.

To spur the creation of optical components that are far smaller and smarter, earlier this year Nanovation pledged $90 million over six years to finance research at MIT in the field of microphotonics. The goal is to emulate the integration of transistors and other electronic devices onto a chip by shrinking optical switches, fibers, lasers and detectors, and stringing them together on a single optical circuit. Just as stuffing together more and more transistors, diodes and capacitors has greatly multiplied the speed and power

Dialing for Dollars

This spring, a small startup called Xros unveiled its optical switching technology. The Sunnyvale, Calif.-based firm had no product sales and was, by its own estimate, a year from a commercial product. But one week after the demo, Nortel Networks announced it was paying $3.25 billion for the company. Seven days later, Nortel shelled out $1.43 billion for Coretek, a small Wilmington, Mass.-based firm. These deals came just months after Nortel spent $3.25 billion for Qtera, a startup in Boca Raton, Fla. The reason for the $8 billion buying spree? Simple, says Nortel: Each startup had a piece of technology critical to building an "all-optical Internet" capable of carrying more and more data at ever-increasing speeds.

Nortel isn't the only company to entertain a vision of assembling an Internet that delivers its data exclusively through the fast, high-bandwidth medium of fiber optics rather than having to resort to electronics at key points in the network. Its competition includes the major suppliers of optical networking systems—Cisco Systems, Lucent Technologies, Paris-based Alcatel and Ciena. "They're all looking at how to develop an all-optical Internet," says Brian Van Steen, a consultant at RHK, a San Francisco-based telecom research firm.

It's the latest phase in the competition among these telecom heavyweights to refine and extend optical technology. In the last couple of years, they have gained strong footholds in dense wavelength division multiplexing (DWDM), a technology that enables many different data streams to travel along a single optical fiber. Now they hope to complete the optical connection, gaining the necessary optical switching technologies through internal R&D and acquisitions *(see table)*. This race puts a premium on companies, ranging from Agilent to Xros, that hold promising new switching technologies.

"All-optical cross connects and all-optical switches are really just starting to move into the market," says Neil Dunay, an analyst at KMI in Newport, R.I. Dunay says telecom carriers are testing all-optical networks using "live" traffic but have not implemented such networks for their customers. He predicts it will be two years before the long-haul networks go all-optical, and even longer before local transmission does the same.

There will be plenty of reward for the winners. RHK estimates the 1999 global market for optical networking at $31 billion. The company predicts that the market for DWDM and other optical devices—the fastest-growing segment of the networking business—will grow from $8 billion in 1999 to more than $41 billion in 2003.

If one of the established heavy hitters in telecom fails to dominate this market, several startups wait in the wings. Among them is Columbia, Md.-based Corvis. Founded in 1997 by David Huber (who earlier started Ciena, a company that struck it rich pioneering DWDM), Corvis has raised $300 million from some of the top venture capital firms. By eliminating the slowdowns when optical signals are converted to electrons and back to photons and providing ultra-long optical transmission without electronic regeneration, Corvis just might be one of the winners in the race for the all-optical Internet.

—Neil Savage

Building Tomorrow's Optical Internet

COMPANY	RECENT MOVES	STRATEGY
Alcatel	No major acquisitions	Already a leading player in DWDM, the telecom giant is spending heavily on R&D to develop optical devices
Cisco Systems	Bought ArrowPoint Communications (May 2000) for $5.7 billion; Pirelli Optical Systems (Dec. 1999) for $2.15 billion; Monterey Networks (Aug. 1999) for $500 million	Gained Internet switching technology from ArrowPoint; DWDM technology and optical switching devices from the Pirelli and Monterey acquisitions
Ciena	Acquired Lightera Networks (March 1999) for $552 million	An early pioneer in DWDM, looking for a business comeback by providing intelligent optical switching
Corvis	Testing its all-optical devices with Broadwing Communications	Leverage technology for ultra-long optical transmission and optical switching to provide an all-optical network
Lucent Technologies	Micromirror-based optical switch is scheduled **to be installed this year**	Relying on internal R&D to develop optical devices; **a leader in microelectromechanical systems**
Nortel Networks	Bought Qtera (Dec. 1999) for $3.25 billion; Xros (March 2000) for $3.25 billion; Coretek (March 2000) for $1.43 billion	Spending heavily to acquire the necessary technologies to put together an all-optical Internet

of microelectronics, both MIT and Nanovation are betting that integrated microphotonics circuits will deliver similar advances in performance.

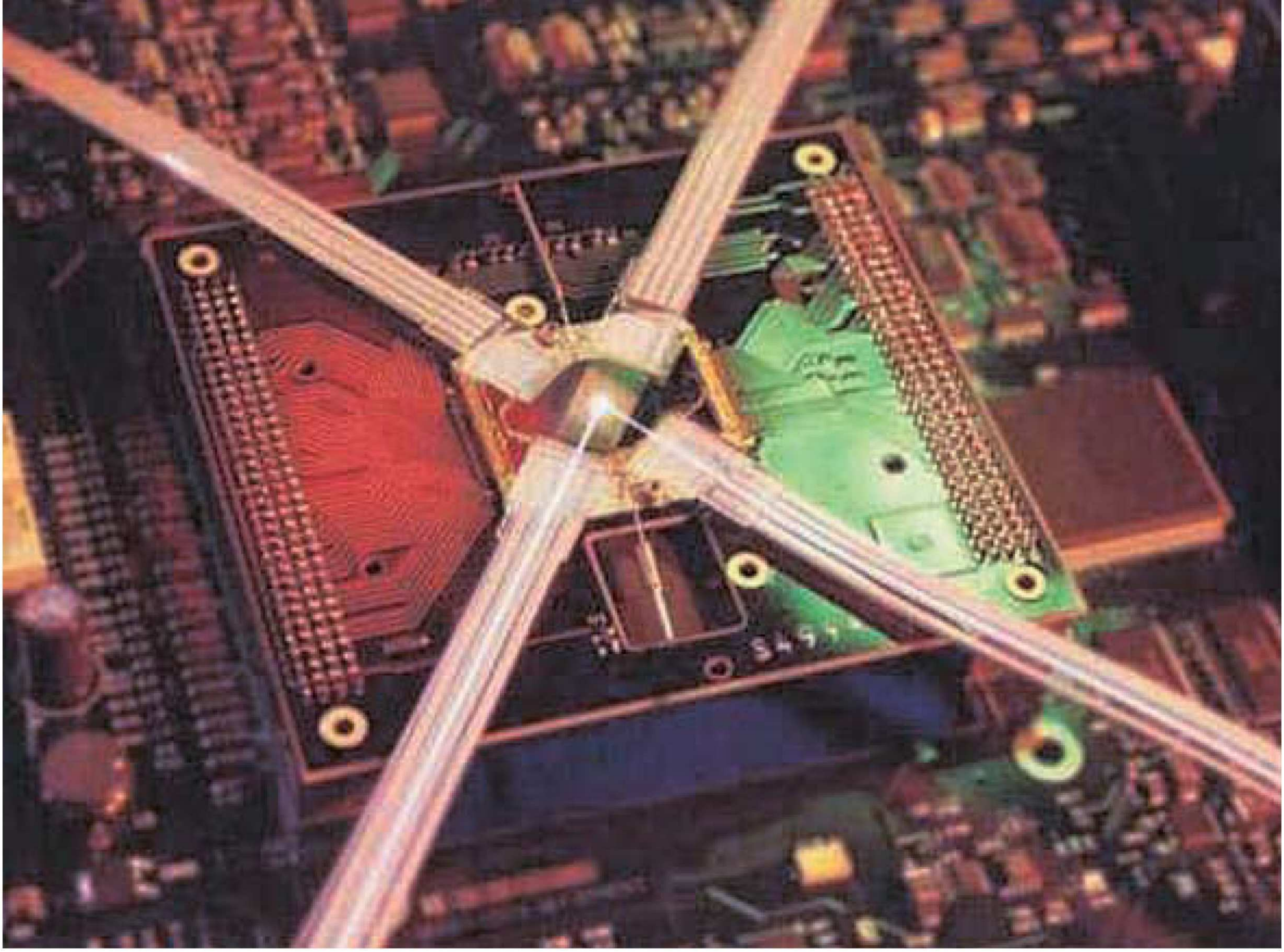
Nanovation's short-term interest is in delivering smaller, more efficient network devices, including simple switches (this spring the company introduced an initial line of such products), but down the road the company hopes integration will deliver more sophisticated and functional optical devices. "This is like the very early days of integrated circuits," Bjorklund says. "The day after they invented the integrated circuit they didn't go from individual transistors to the Pentium. That took thirty years. But there is a lot of value added by putting twenty or thirty transistors on one chip."

Before Nanovation—or anyone else—can become the Intel of microphotonics, they must learn to tame the unruly photon. Electrons have proven useful because they have a charge and are therefore relatively easy to manipulate by, say, applying a voltage. That makes it possible to route electronic signals around microscopic integrated circuits; it also makes it possible to utilize electrons to manipulate and store information. It is these qualities that have made electrons so valuable in microelectronics and computing.

Photons, however, are much less malleable characters than electrons. They're great for speeding information from one place to another over long distances, but it's tough to control them. Try sending them around a sharp corner, for instance, and they scatter wildly.

Dreams of taming photons and using them in integrated optical circuits are not new. But recent research in industrial telecommunications labs, universities and at least a dozen startup companies is opening up ways to better invoke the required mastery over photons.

One key to this work could be the fabrication of smaller and more efficient waveguides that could be used to control the flow of photons in integrated optical circuits. To gain higher levels of functionality for optical



Bright crossroads: Agilent's switch uses waveguides to direct light to an intersection, where tiny bubbles deflect the light to an outgoing fiber.

circuits—and gain a higher level of control over photons—Nanovation and MIT, among others, are exploring waveguides fabricated in novel materials such as silicon-silica hybrids and indium phosphide. These materials confine light so strongly that beams with a wavelength of 1.5 micrometers—the standard for telecommunications—can be contained in waveguides about half a micrometer wide. These waveguides can also make tighter turns—about a thousand times tighter than the millimeter-scale bends achieved in earlier waveguides—without spilling their contents.

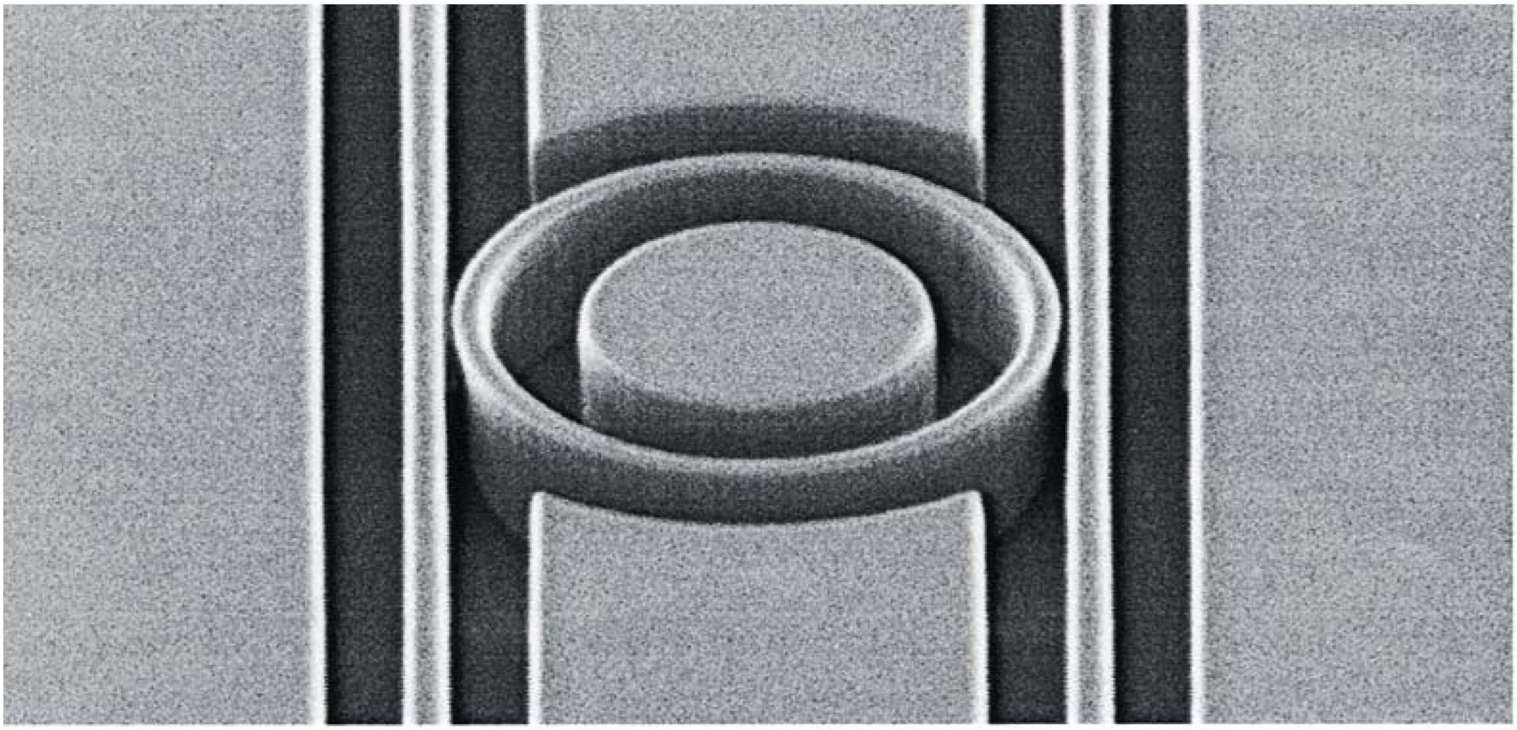
Photons confined in these tiny structures take on odd and potentially useful behaviors. For example, relatively small voltages can entice photons in the waveguide to jump between adjacent channels. And rings as small as 5 micrometers in diameter—about the width of a human hair—can pluck lightwaves of a given wavelength out of one waveguide and shoot them down another, providing a color-selective switch.

Such advances are opening up possibilities for integrated photonic chips. And that is boosting hopes for smarter optical switches that will better distribute the power of fiber optics. For instance, an optical chip could select one wavelength of high-bandwidth light off the fiber passing through your neighborhood and divert that data-rich wavelength to your home, where another optical chip would grab your phone calls, high-definition TV shows and Web browsing. This type of networking is already being explored in regional systems. Future microphotonics could bring it to the living room.

The promise inherent in integrated photonic circuits, however, extends beyond fiber-optic networks. In much the same way integrated optical devices could improve how data is transmitted in long-range communication systems, they could also facilitate the sharing of information in the microscopic realm where computers talk to themselves. For years physicists have been dreaming of computing that relied on photons, rather than electrons. That idea may or may not become a practical reality; while it has proven possible to use photonics for logic and memory functions, electronics remain much better at the job.

Still, photons may be the key to faster computer chips, which are suffering from their own form of electronic bottleneck. Increasingly, the speed of transistors and integrated chips are outpacing the metal wires and cables that connect them—the wires can't carry data fast enough. "Whereas microphotonics is giving you complex optical circuits for communications, now it's also required at the other end—the very localized end—to make the next

AGILENT TECHNOLOGIES



Light corral: Nanovation's optical resonator (center), about 10 micrometers across, is used to channel photons between waveguides (vertical bars).

NANOVATION TECHNOLOGIES

generations of microprocessors," says MIT's Kimerling.

Wires of Light

PHOTONIC WIRING BETWEEN transistors could make faster chips, while photons zipping between chips could turbocharge your computer's motherboard. Imagine thousands of laser beams crisscrossing within your computer, and you wouldn't be far off.

Engineers at companies such as Honeywell, Sun Microsystems and IBM, as well as at universities around the world, are already testing arrays of light-emitting diodes and laser beams that could serve as the "bus" that transports information across a motherboard from microprocessors to memory chips to display screen and back. Initial applications for these systems will be in high-end computing. Honeywell, for example, is using optical interconnects to link microprocessors, creating compact, powerful parallel computers.

Squeezing light inside individual computer chips to replace metal interconnects may not be far behind. The ability to etch smaller transistors on silicon wafers has steadily increased the power of computers. The problem is that as transistors get smaller and smaller, they can switch much faster than they can communicate with each other, slowing down the overall functioning of the chip. While chip makers think they can squeeze out enough performance from the shrinking metal wires that connect electronic devices to make the next generation of chips, they are turning to photons for future batches. Sematech, the international association of semiconductor makers, estimates that its members will begin to exhaust improvements to metal interconnects by 2008. The use of light-based interconnects is one of the few feasible solutions, according to Sematech.

Optical interconnects in computing "is still speculative," says David A.B. Miller, an electrical engineer at Stanford University. But, he predicts, you'll see such interconnects "in mainstream computing by the end of the decade. That's not a ridiculous statement to make."

Whether working on telecom or computing applications, however, the ultimate goal of optics researchers is to make integrated microphotonic circuits as ubiquitous as today's microelectronic chips. "The ideal solution is to have something able to do the mirror function, the switching function and the waveguiding function all within one platform," says Shawn Lin, a physicist at Sandia National Laboratories in Albuquerque, N.M. Lin is using photonic crystals, tiny silicon-based structures that confine light with exquisite efficiency, to make his own set of lasers, amplifiers, waveguides and other devices for lightwave circuits. Getting all of these devices to work together on a single wafer, says Lin, will put photonics on "holy ground," just as moving the electron from a vacuum to the silicon wafer unleashed the power of electronics. What's more, Lin thinks integration will take hold in photonics much faster than in microelectronics.

Lin's voice falls to a whisper as he discusses the future of microphotonics, as if revealing the full potential of capturing light on a chip could somehow jinx his chances for success. "All the necessary inventions, the materials issues have been solved," says Lin. "It's up to our imagination to come up with innovative devices and to build the basic building blocks. There are large amounts of money just waiting to see breakthroughs happen."

Those breakthroughs are likely to come from the dozens of industrial and university labs that are working on integrated photonics, as materials scientists like Lin work with optical theorists to perfect waveguides, lasers and other basic building blocks, fabrication experts figure out how to integrate these devices in a high-density chip, and systems engineers optimize circuitry. Just as today's micromirrors and tiny bubbles are beginning to switch on the full potential of the Internet's high-speed optical backbone, tomorrow's optical chips promise to unleash the photon's raw power and speed to fundamentally change how information is transmitted. ◊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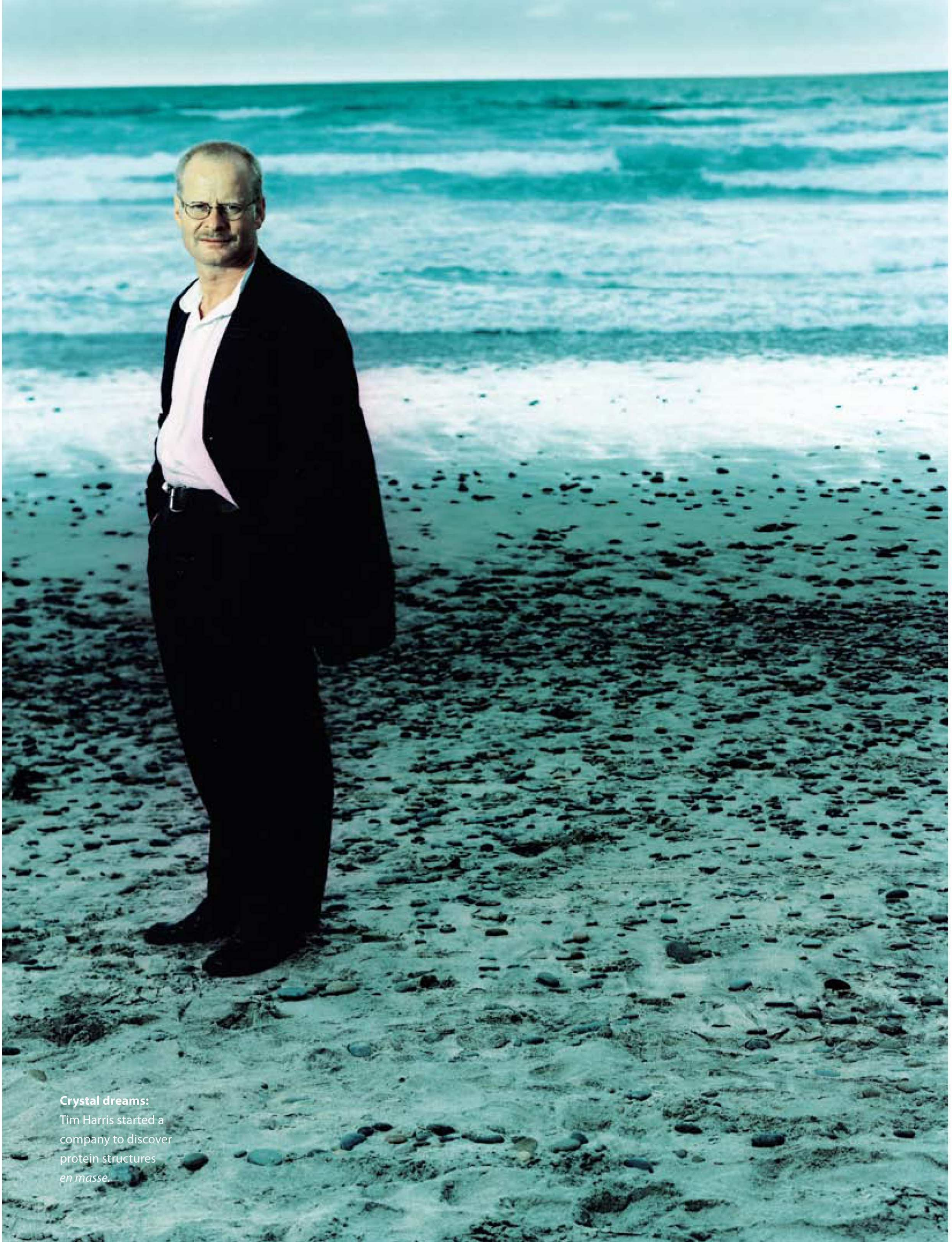


Crystal dreams: Tim Harris started a company to discover protein structures *en masse*.

The Next Wave of the Genomics Business

The Human Genome Project is in the news. But entrepreneurs are already catching the next wave—3-D protein structures. The payoff will be drug discovery at genomic speed. BY KEN GARBER

JAY KNOWLES IS ENJOYING HIMSELF. THE BIOTECH EXECUTIVE SITS IN HIS SAN DIEGO OFFICE, WHERE HE DIRECTS business operations for Structural GenomiX (SGX). SGX, a startup company, has raised nearly $40 million in venture capital since its founding a year ago and is now turning away investors. "Being the next wave of the genomics business, everyone's flocking to give us as much money as they possibly can," Knowles boasts. And, he adds, several large pharmaceutical firms are eager to buy SGX's product: three-dimensional protein structures, those intricate models with loops and whorls that lend a touch of the fanciful to the pages of scientific journals like *Science* and *Nature.* "We have lots of deals on the table," says Knowles.

Suddenly, Knowles' boss, president Tim Harris, bursts into the room. "Vertex has just cut a structural genomics deal with Incyte," he says. "Bastards. This is war."

PHOTOGRAPHS BY ANNE HAMERSKY

Knowles is stunned. Before coming to SGX, he was director of R&D planning for Vertex Pharmaceuticals, the visionary Cambridge, Mass., drug company that specializes in structure-based drug design—the construction of medicines atom by atom, fitting drugs like finely cut jewels into protein settings. Out of courtesy to his former employer, Knowles has avoided raiding Vertex for employees. But if Vertex, with the help of Palo Alto, Calif.'s high-flying Incyte Genomics, wants to compete head-to-head with SGX in the emerging field of "structural genomics" (the large-scale discovery of precious protein structures), the truce is history. "Anybody you want to pull out of that place, go ahead," says Harris. "The gloves are off."

A few frantic phone calls later, however, and it's clear that it's a false alarm. Vertex has merely bought access to Incyte's stockpile of human genes. But Harris and Knowles remain on red alert, prepared to battle any company that threatens SGX's early lead in a field that they claim will revolutionize drug discovery. "We'll see other groups jump on the bandwagon," says Harris. "You can bet your life."

Structure-based design should lead to exquisitely specific new drugs, avoiding the side effects that doom otherwise promising compounds to the pharmaceutical dustbin.

Molecules to Medicine

SGX'S AMBITIOUS GOAL IS TO AUTOMATE the production of information about protein structures, and sell the results to large drug companies. It's a business plan with obvious precedent. After all, it was the introduction of high-speed machines for DNA sequencing that allowed quick-moving and well-financed companies such as Incyte to amass private empires of genetic data. Using the same technology, the public-sector international Human Genome Project is expected to publish (sometime this year, ahead of schedule) a working draft of the complete human genetic makeup.

That's where Knowles' interrupted pitch picks up: Mass production of protein structure, he believes, is the natural successor to mass production of DNA sequence. After all, those 100,000 or so genes are merely blueprints for making proteins—the versatile molecules that perform nearly every vital function in our bodies. Yet the function of most proteins remains unknown. Thus, the urgent task is to figure out what proteins do and how they work, and there is no better starting point than their three-dimensional shape. Until now, however, "solving" these protein structures has been a notoriously difficult undertaking.

Automating could yield big gains, not only for basic science, but also for what Harris calls the "bloody hard" business of discovering new drugs. According to this 20-year industry veteran, a significant jump in the number of available protein structures could transform how drugs are created.

Today, the vast majority of drugs are still found by hit-and-miss methods, albeit on a massive scale. The world's top pharmaceutical companies have sunk billions into automated systems that can synthesize and test hundreds of thousands of chemical compounds a week, hoping to turn up a few "hits" against a protein target. (Most drugs on pharmacy shelves work by attaching to proteins, activating or disabling them.)

Structural genomics proposes turning traditional drug discovery on its head, putting protein structures first and using them to design new drugs from the ground up, a process known as "rational drug design" or "structure-based drug design." Instead of relying on luck, with a three-dimensional structure as a starting point chemists can use the details of its shape to create a chemical compound that fits precisely. Drugs that result should, in theory, be exquisitely specific, avoiding the side effects that often doom otherwise promising compounds to the pharmaceutical dustbin.

Audacious Goals

ALTHOUGH STRUCTURE-BASED DESIGN has led to some breakthrough medications, such as HIV protease inhibitors (including Vertex's Agenerase) and Glaxo's flu treatment Relenza, the list quickly dwindles after that. Drug firms still largely rely on the mass screening approach, in part because protein structures are so hard to come by.

Mass production of protein structures could change all that. Today, even the biggest pharmaceutical companies only manage about twenty new protein structures a year. Yet, by 2003, SGX proposes to solve that many each week—every week. It's an incredibly audacious plan, but Harris is confident. "I know that if we don't do it, some other bugger would," he says. "Because it's absolutely there waiting to be done. It's the next step."

In fact, Harris already has competition. Less than a mile away as the crow flies, but separated from SGX by a deep ravine, is the Genomics Institute of the Novartis Research Foundation, a nonprofit with close ties to Swiss drug giant Novartis *("The Bell Labs of Biology,"* TR *March/April 2000).* As *TR* went to press, scientists at the Genomics Institute were about to unveil a new spin-off venture called Syrrx that plans to harness auto-

Entrepreneurs Seek Structure

COMPANY	LOCATION	HIGHLIGHT
Structural GenomiX	San Diego, Calif.	Has an early lead in the structural genomics race thanks to a $40 million venture capital infusion
Syrrx	San Diego, Calif.	Academic spin-off has its technology platform in place, and plans to generate 1,000 structures in 2003
Structure Function Genomics	Princeton, N.J.	Will use nuclear magnetic resonance (NMR) to dete mine structures
Astex Technology	Cambridge, England	Concentrating on protein-drug complexes of interest to pharmaceutical companies

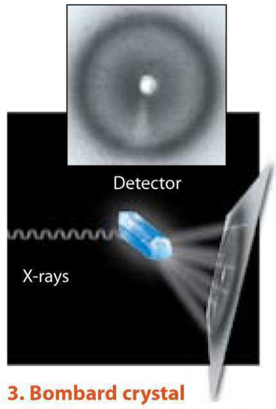
From Proteins to Drugs

X-ray crystallography reveals a protein's 3-D structure

BETSY HAYES

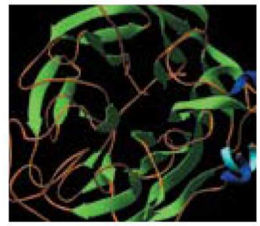
1. Purify protein. A protein is produced in genetically modified organisms, such as bacteria, then isolated.

2. Crystallize protein. The protein is coaxed to form a crystal. Often a time-consuming, trial-and-error process.

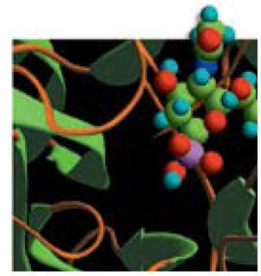


3. Bombard crystal with X-rays. High-intensity photons are deflected off of the protein's atoms to produce a signature diffraction pattern.

4. Compute 3-D structure. The X-ray diffraction pattern must be translated into a model of the protein—a computation-heavy task.



5. Rational drug design. With the protein structure in hand, scientists can begin custom-building a chemical to block or enhance its function.



mation and robotics "to solve [protein] structures at what would be considered, in years past, almost an impossible rate," says director of business development Ned David.

Other contenders include Astex, in Cambridge, England, and Princeton, N.J.-based Structure Function Genomics. More are coming. "It's going to be very crowded," says Harren Jhoti, acting CEO of Astex.

Nor is it only the private sector that's interested. The National Institutes of Health (NIH) recently launched the Protein Structure Initiative, which will spend up to $125 million in its first five years. The governments of Canada, Germany and Japan are also planning major structural genomics initiatives, and overall spending could eventually rival the multibillion-dollar Human Genome Project. The NIH alone hopes to generate 10,000 structures by the end of the decade.

The startup companies are even more ambitious. By 2003, Syrrx projects, it will be solving about 1,000 structures a year. SGX, if it meets targets, will be doing 1,350. The numbers go up from there. These are truly bold figures given the painfully slow pace at which three-dimensional protein structures have been unraveled in the past. For perspective, consider that in almost half a century since the first protein structure was solved in 1957 (the muscle protein myoglobin), a total of only about 2,000 unique protein structures have been deposited in the Protein Data Bank, the international structure repository.

Indeed, the promises being made by SGX and Syrrx are so far out of line with past experience that in the eyes of some experts they amount to fantasy. "Completely unreasonable," says prominent University of California, Irvine structural biologist Alex McPherson. "The technology is simply not there, and it's not going to be there for a fairly long time. I just don't understand where they're getting numbers like that."

A Daunting Challenge

MCPHERSON HAS REASON TO BE SKEPTICAL. Mass-producing protein structures is going to be a lot tougher than DNA sequencing. DNA is a simple linear code of four chemical letters, while proteins are composed of twenty different amino acids and fold into complex, largely unpredictable arrangements of sheets and loops. Although scientists have long tried, with the help of computers, to predict protein structure directly from the DNA blueprints, they're still a long way off, even for the simplest proteins *(see "Blue Gene vs. Proteins," p. 56)*.

Instead, both Syrrx and SGX will be attempting to automate the most widely used empirical approach, known as X-ray crystallography. With this method, a protein is first purified, then coaxed to form a crystal. At that point, scientists shoot concentrated radiation into the crystal, exploiting the pattern of scattered rays to reconstruct an atom-by-atom model of the protein in its crystalline form.

Although that process may sound straightforward, it's not. Many proteins, for instance, are extremely difficult to isolate, and the crystallization process itself is anything but cookbook. Temperature, acidity and salts must be fine-tuned to cajole a tiny, delicate crystal out of solution. Finally, converting the X-ray data into a three-dimensional model of a protein's shape is often an "agonizingly difficult" problem, says University of California, San Diego crystallographer Lynn Ten Eyck. "There's a lot of human judgment applied to that problem at present," he says. "And human judgment takes time."

So much time, that in the past crystallographers sometimes spent years doggedly pursuing the structure of a single protein. And because of its great difficulty, crystallography has a well-earned reputation as a professional guild open to only the most obsessive and highly skilled breed of scientist. "It's not as much of a heroic effort as it was, although it is still very difficult," says John Norvell, who directs the Protein Structure Initiative.

Even though automating X-ray crystallography is a bit like creating *haute cuisine* without chefs, SGX and its competitors are betting millions that they can transform this costly (about $200,000 per protein), tedious enterprise into a cheap, fast and reliable industrial process. "It's very doable," says Harris, who spent the last decade automating science at British drug company Glaxo and California biotech firm Sequana Therapeutics. Harris believes production rates can be increased "by an order of magnitude, or even two orders of magnitude"—a hundred times faster than today.

Syrrx co-founder Ray Stevens is also

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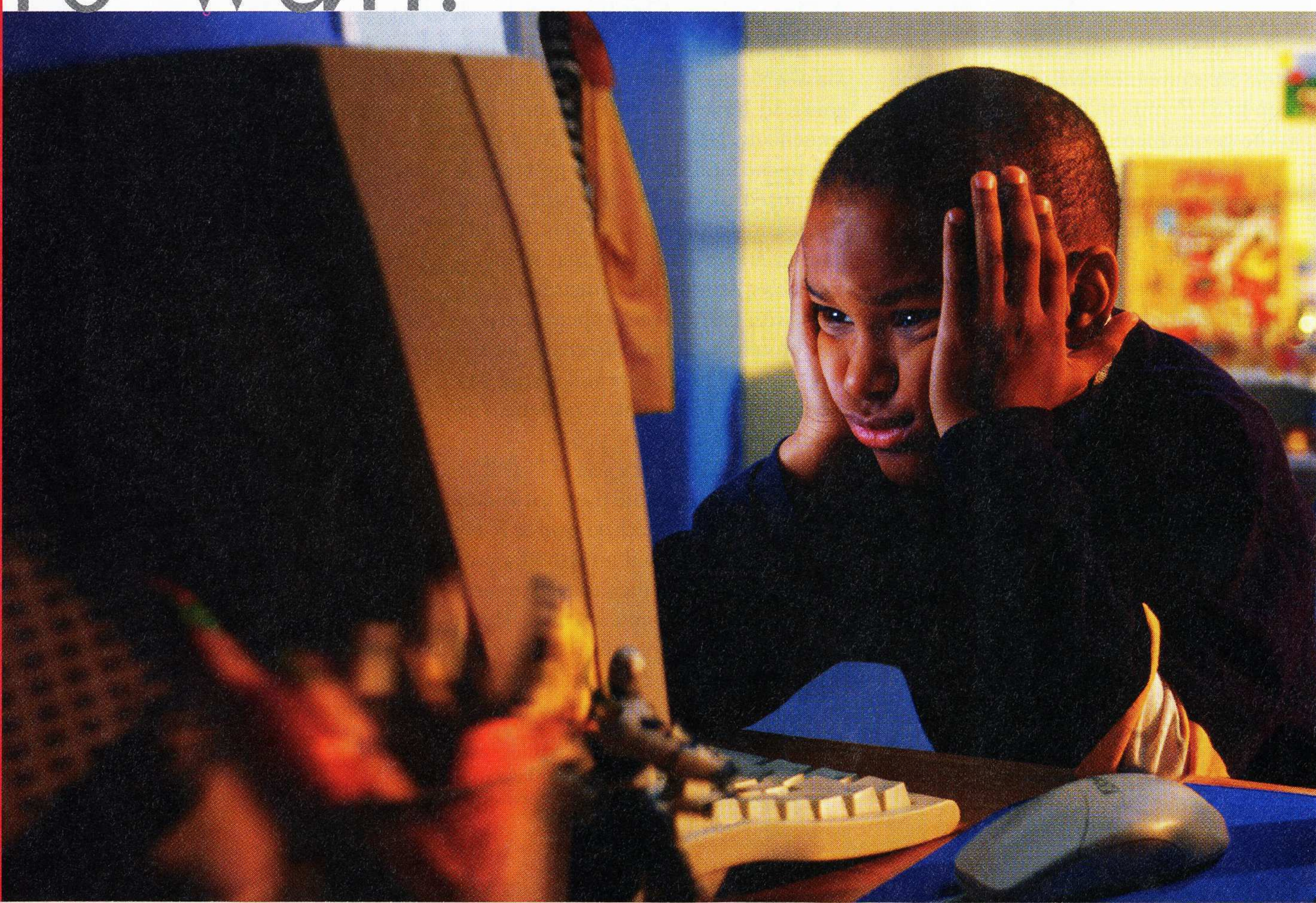

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making bold predictions. "If we sit around [just] talking about it, it's never going to happen," he says. "It's going to take quantum leaps, and we believe the quantum leaps are going to be in automation."

Filling the Pipeline

THE FOUNDERS OF BOTH SGX AND SYRRX have the credentials to back their claims. Colleagues credit SGX scientific co-founders, Columbia University biophysicists Barry Honig and Wayne Hendrickson, with coining the term "structural genomics." Hendrickson is a celebrated crystallographer who invented an ingenious method for tackling otherwise unsolvable proteins. Honig, who has written widely used computer programs for analyzing and predicting protein structures, knew that more solved structures would make his job much easier. "These [prediction] methods depend on data," he points out.

There's no single breakthrough technology that's made structural genomics feasible. Rather, a combination of more DNA sequence data, powerful X-ray "beamlines" and high-speed computers have sped up the entire process and made it more reliable. By the late 1990s, says Honig, he and Hendrickson had concluded "the time was ripe" for a concerted assault on the protein universe.

The idea of industrializing crystallography also fired the imagination of Ray Stevens, a chemist who invented a novel "micro-crystallization" system for making protein crystals from droplets up to a hundred times smaller than usual—a key element in Syrrx's system. Working feverishly within the walls of the Novartis Institute, Stevens and a team of engineers have already built a prototype system for fully automating X-ray crystallography. Machines sporting intricate mazes of glass flasks, rubber tubing, test tubes and electrical harnesses include a crystallization robot that can perform 139,000 experiments a day and process a million time-lapse photo images of crystal growth. "If you do this one protein at a time, there is no way in the world you can reach those numbers," Stevens says. "Everything is set up in parallel."

That doesn't mean everything will work. "We're going to have a high failure rate at first," Stevens readily admits. In 2002, Syrrx's first year of full-scale production, fewer than two percent of its proteins are expected to yield three-dimensional structures. But since the company plans to test 60,000 proteins, that still means nearly 1,000 successful structures coming out the end of the pipe.

A thousand novel structures a year would, in Ned David's words, "make drug discovery move at a genomics pace." While SGX is compiling a database of structures to sell to pharmaceutical companies, Syrrx will go a step further by developing lead drug compounds using computer-based rational design techniques. To do this, it will model virtual libraries of chemicals for proper fit to protein structures. "We'll be able to dock 200,000 compounds [to a protein] in under a day," says David. "The value here is making drugs, and making them fast."

That's the promise. In the near term, however, both startup firms will simply be racing to generate as much structure data as possible. That's because, as on the Internet, commercial success may go to whoever gets there first with the most. "We have momentum, and we have first-mover advantage," says Harris, whose company has found about a dozen structures in its first six months of operation. "Believe me, we are going to exploit that, ruthlessly. I like that word, because I mean it."

Working feverishly within the walls of the Novartis Institute, Stevens' team of engineers has already built a prototype system for fully automating X-ray crystallography.

Keeping the Peace

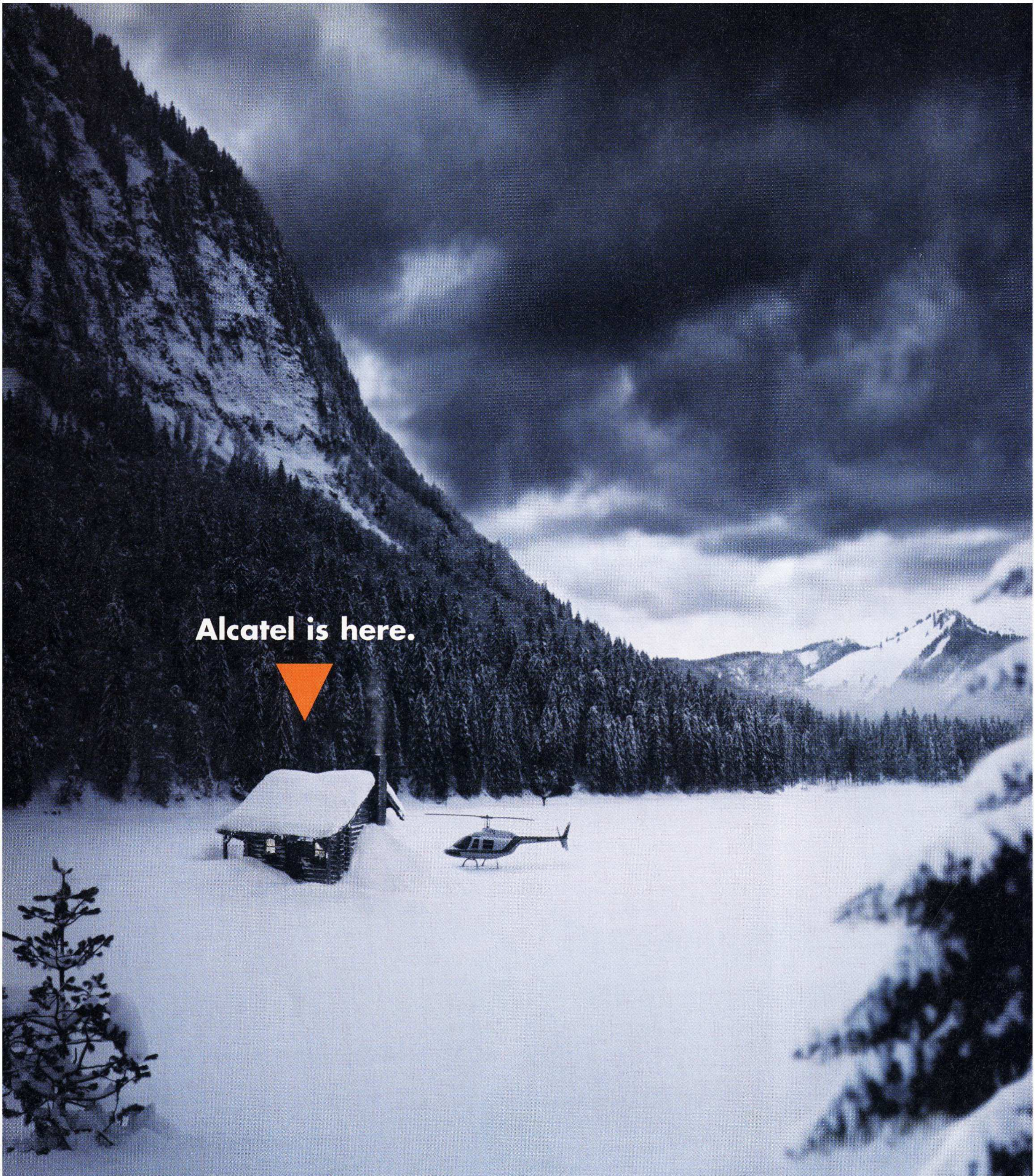
WHILE THE STARTUPS JOCKEY FOR ADVANTAGE, the government-backed projects plan to assemble a body of common knowledge that could help all researchers—public and private—gain access to protein structures. In mid-April, the Wellcome Trust, the giant British biomedical research foundation, hosted a meeting of government scientists and academics in Cambridge, England, to work out ground rules for a coordinated worldwide effort to discover protein structures *en masse.* The NIH hopes that 10,000 proteins, carefully chosen, will be enough to catalogue roughly 1,000 different protein "folds," the basic types of loops and twists common to all proteins.

Once every fold is in their library, scientists should be able to use computers to predict, with reasonable accuracy, the structure of any of the remaining 90,000 or so human proteins directly from DNA sequence. That will be a critical step in giving meaning to the raw DNA data generated by the genome projects. "In the past, we found the function of a protein and then found the structure," says the NIH's John Norvell. "Now we'll be in the position to find the structure and ask,

Structural Genomics Becomes International Big Science

INITIATIVE	HIGHLIGHT
Protein Structure Initiative	$125 million-plus effort funded by the U.S. National Institutes of Health to solve 10,000 protein structures in 10 years
Protein Structure Factory	The German Ministry for Research and Technology is funding several acdemic teams to perform high-speed structure analysis of medically important proteins
NMR Park Project	Japan's Institute of Physical and Chemical Research (RIKEN) is using NMR to determine the structure of mouse proteins
Structural Biology Industrial Platform	Several major European pharmaceutical firms are part of this 16-company consortium in structural genomics
Structural Diversity Pilot Project	Academic collaboration led by Rockefeller University

The automators: Ray Stevens (left) and Ned David founded Syrrx to turn crystallography into assembly-line science.


Alcatel is here.

'What does this protein do?'"

With both private and public sectors diving into structural genomics, some worry that a poisonous competition will develop. An obvious precedent: the Human Genome Project versus Celera Genomics, the Rockville, Md., company that appears poised to win the race to complete the human DNA sequence *(see "The Gene Factory,"* TR *March/April 1999).* Efforts to work together were dashed by Celera's refusal to share its private data on the government's terms.

Could the same scenario unfold in structural genomics? "I suspect there will be some friction," says Phil Bourne, who co-directs the Protein Data Bank. Open publication of data will likely again be the flash point for conflict. The NIH (and its international partners) agreed at the Cambridge meeting on quick release of information into the public domain.

SGX executives say they will have to protect their structures, through both secrecy and patents. Stevens, however, says Syrrx is moving to avoid conflict by taking the extraordinary step of depositing much of its data into the Protein Data Bank. "There's a lot of lessons we can learn from Celera and the Human Genome Project," says Stevens. "We would like not to make those mistakes....The information should become public."

Not that Syrrx is giving away the store. The company will keep certain structural details important for drug development under wraps, and it has also filed patents on its robots. But Stevens has promised that Syrrx will let the government use these for a nominal fee. "This is a two-way street with the public effort," he insists.

Whether or not it's possible to avoid public-private strife, it's clear that structural genomics is acquiring tremendous momentum. For crystallographers, that means dramatic changes ahead. Lynn Ten Eyck, who has been a card-carrying member of this insular field for thirty years, sees the writing on the wall. "These automated systems will just steamroll anyone who's not using them," he says. "It's like the Industrial Revolution."

Ten Eyck does not intend to fight progress. In fact, he's joined a group of fellow academics seeking a structural genomics grant from the NIH. As Ten Eyck sees it, mass production of protein structures is the inevitable next step in biology's rapid transformation from a basic science into an "engineering discipline." The payoffs should include not only structure-based drugs, but also better diagnostics and perhaps even the ability to reverse birth defects. "There's a vast array of things you can do if you actually understand the biology well enough," says Ten Eyck. "This is not something that's going to happen tomorrow, but we're watching the transition start." ◊

Some worry that a poisonous competition could develop in the structural genomics field. An obvious precedent: the Human Genome Project versus Celera Genomics.

Blue Gene vs. Proteins

Three years ago, IBM's Deep Blue computer finally defeated chess grandmaster Garry Kasparov. Last December, IBM announced it would spend up to $100 million over the next five years on a new supercomputer, dubbed Blue Gene, designed to conquer another as-yet-undefeated opponent—biology's "protein folding problem."

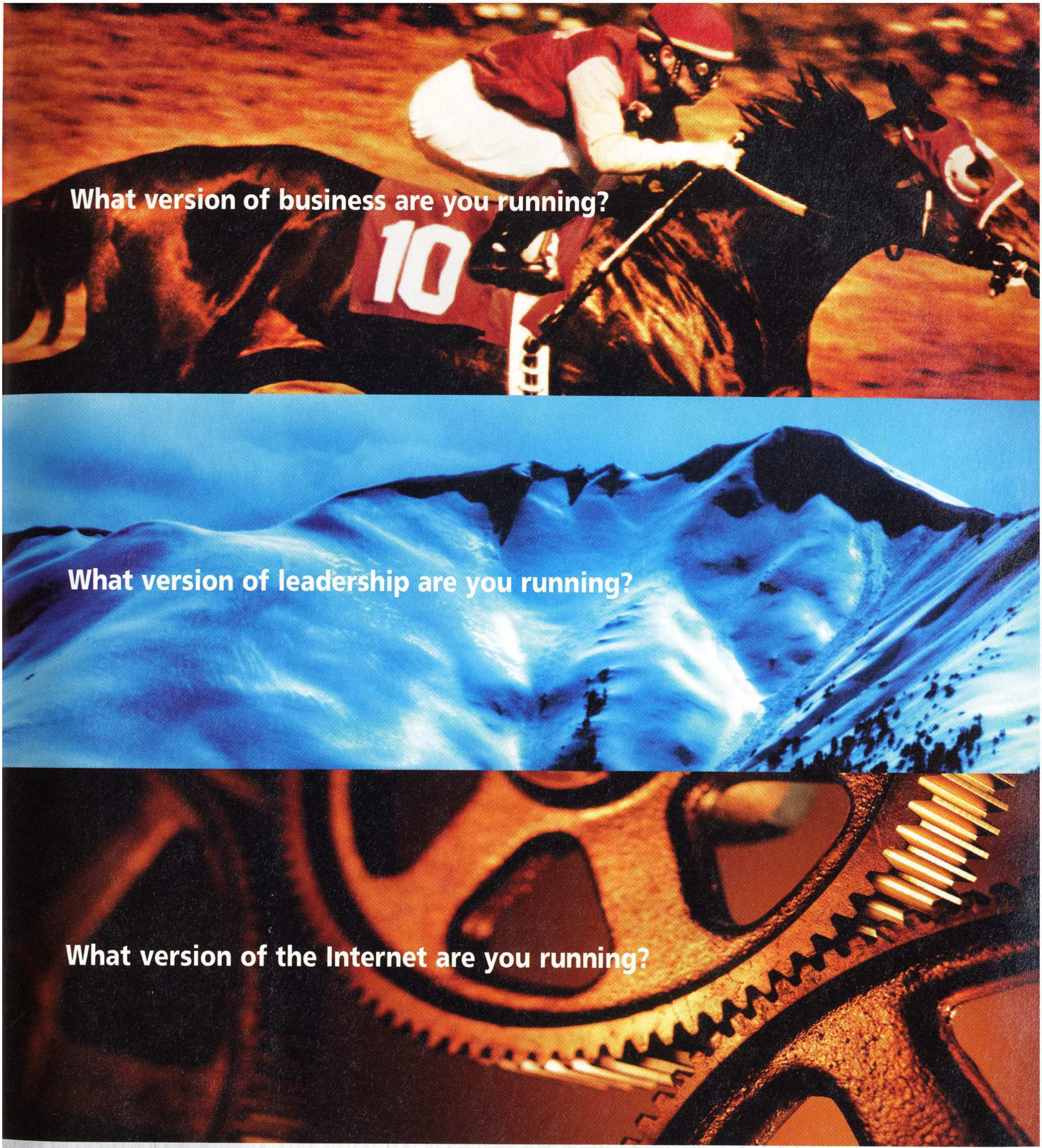
The protein folding problem has stumped biologists ever since the early 1960s, when they first cracked the genetic code: DNA is "transcribed" into RNA which is then "translated" into strings of amino acids. Once chained together, these proto-proteins take just a millisecond to scrunch up into a wad whose folds and crevices hold the key to a protein's specific role in the cell. Yet despite remarkable advances in other areas of biology, scientists still don't know how to predict a protein's shape from its DNA sequence.

Blue Gene will tackle the protein-folding problem with immense computing power. According to IBM, Blue Gene's massively parallel architecture will be able to carry out more than one quadrillion operations per second (one petaflop). That's about 500 times quicker than today's fastest computer. "Think about building a skyscraper 500 times higher than the tallest skyscraper," says Paul Horn, senior vice president of IBM Research.

Once built, Blue Gene will spend an entire year computing the predicted physical interactions between each atom of an average-sized, 150-amino-acid protein as it folds. To model the process, Blue Gene's creators will use sophisticated mathematical models of atomic interactions known as "force fields." No one yet knows how accurate force fields are for predicting the way proteins fold, because the computer power does not yet exist to fully test them. Blue Gene, its designers say, will change that. According to Dennis Newns, software architect for the project, "We're going into this as sort of 'blue sky' science: to find out what's happening. Are the force fields good enough?"

Many scientists think they aren't. That's one reason startup companies and government funding agencies are now spending millions to come up with protein structures the old-fashioned way—through grueling lab experiments combined with predictions based on known protein shapes *(see main story).* "The expectation is that a computer is going to solve the protein folding problem," says Charles Brooks, a prominent computational biologist who works at the Scripps Research Institute in La Jolla, Calif. "It's not."

Of course, many people didn't believe a computer could ever beat the world's chess champion, either. Newns is confident that Blue Gene should be able to solve the folding problem, at least for smaller proteins. "We know the machine is powerful enough to get us there," he says.



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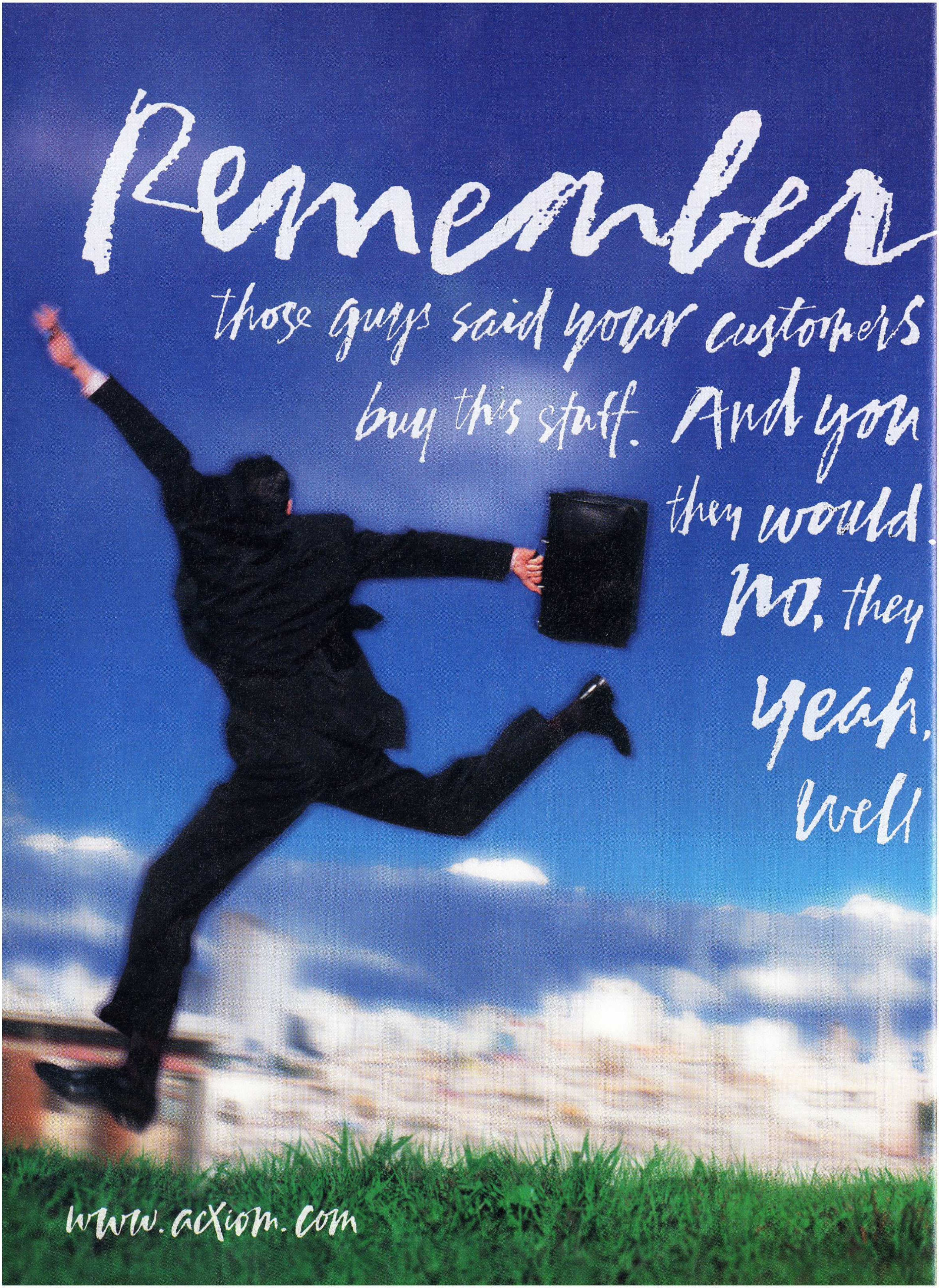
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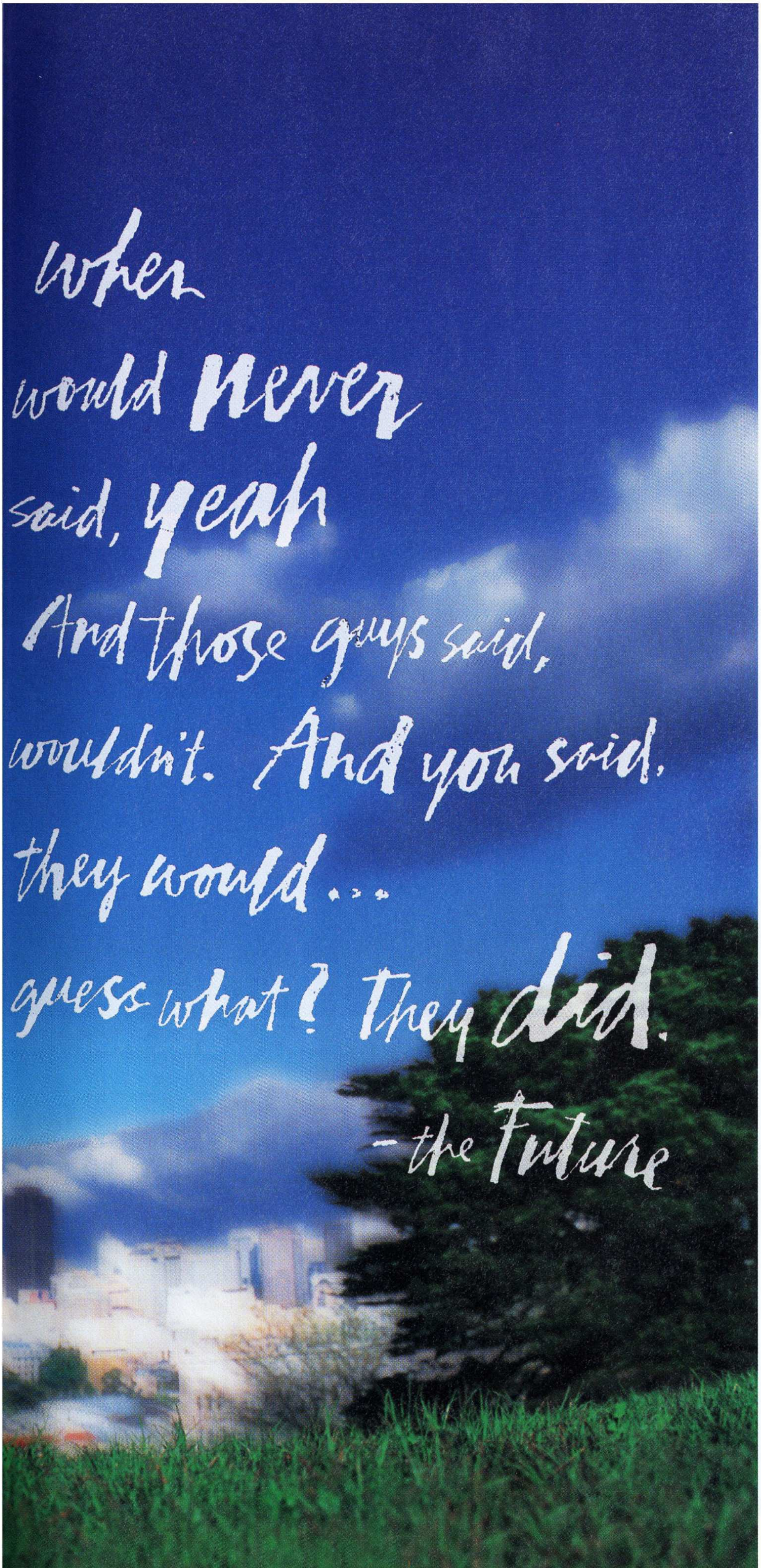

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Into thin air: Sarnoff's video wizardry erases U.S. skier Johnny Mosley from the scene of his triumph at the 1998 Winter Olympics in Nagano, Japan.

Seeing is no longer believing.

The image you see on the evening news could well be a fake—a fabrication of fast new video-manipulation technology.

Lying With Pixels

LAST YEAR, STEVEN LIVINGSTON, PROFESSOR OF POLITICAL communication at George Washington University, astonished attendees at a conference on the geopolitical pros and cons of satellite imagery. He didn't produce evidence of new military mobilizations or global pandemics. Instead, he showed a video of figure skater Katarina Witt during a 1998 skating competition.

In the clip, Witt gracefully plies the ice for about 20 seconds. Then came what is perhaps one of the most unusual sports replays ever seen. The background was the same, the camera movements were the same. In fact, the image was identical to the original in all ways except for a rather important one: Witt had disappeared, along with all signs of her, such as shadows or plumes of ice flying from her skates. In their place was exactly what you would expect if Witt had never been there to begin with—the ice, the walls of the rink and the crowd.

So what's the big deal, you ask. After all, Stalin's staff routinely airbrushed persona non grata out of photos more than a half-century ago. And Woody Allen ushered a variation on reality morphing into the movies 17 years ago with *Zelig,* in which he inserted himself next to Adolf Hitler and Babe Ruth. In films such as *Forrest Gump* and *Wag the Dog*, reality twisting has become commonplace.

What sets the Witt demo apart—way apart—is that the technology used to "virtually delete" the skater can now be applied in real time, live, even as a camera records a scene and instantly broadcasts it to viewers. In the fraction of a second between video frames, any person or object moving in the foreground can be edited out, and objects that aren't there can be edited in and made to look real. "Pixel plasticity," Livingston calls it. The implication for those at the satellite imagery conference was sobering: Pictures from orbit may not necessarily be what the satellite's electronic camera actually recorded.

BY IVAN AMATO

SARNOFF CORP./IOC/USOC

But the ramifications of this new technology reach beyond satellite imagery. As live electronic manipulation becomes practical, the credibility of all video will become just as suspect as Soviet Cold War photos. The problem stems from the nature of modern video. Live or not, it is made of pixels, and as Livingston says, pixels can be changed.

The best-known examples of real-time video manipulation so far are "virtual insertions" in professional sports broadcasts. Last January 30, for instance, nearly one-sixth of humankind in more than 180 countries repeatedly saw an orange first-down line stretched across the gridiron as they watched the Super Bowl. Princeton Video Imaging (PVI) in Lawrenceville, N.J., created that line, stored it in a computer, and inserted it into the live feed of the broadcast. To help determine where to insert the orange pixels, several game cameras were fitted with sensors that tracked the cameras spatial positions and zoom levels. Adding to the illusion of reality was the ability of the PVI system to make sure that players and referees occlude the virtual line when their bodies traverse it.

Any video that has ever been recorded is becoming clip art that producers can digitally sculpt into the story they want to tell.

Last spring and summer, as PVI and rivals such as New York-based Sportvision were airing virtual insertion products, including simulated billboards on walls behind major league batters, a team of engineers from Sarnoff Corp. in Princeton, N.J., flew to the Coalition Allied Operations Center of NATO's Operation Allied Force in Vicenza, Italy. Their mission: transform their experimental video processing technology into an operational tool for rapidly locating and targeting Serbian military vehicles in Kosovo. The project was dubbed TIGER, for "targeting by image georegistration." "Our goal was to be able to fire precision-guided munitions at Serbian military vehicles—just dial in the coordinates and the thing goes," explains Michael Hansen, a young, caffeinated Sarnoff gadgeteer who can hardly believe he was helping fight a war last year.

Compared to PVI's job, the military's technical task was more difficult—and the stakes were much higher. Instead of altering a football broadcast, the TIGER team manipulated a live video feed from a Predator, an unmanned reconnaissance craft flying some 450 meters above Kosovo battlefields. Rather than superimposing virtual lines or ads into sports settings, the task was to overlay, in real time, "georegistered" images of Kosovo onto the corresponding scenes streaming in live from the Predator's video camera. The terrain images had been previously captured with aerial photography and digitally stored. The TIGER system, which automatically detected moving objects against the background, could almost instantly feed to the targeting officers the coordinates for any piece of Serbian hardware in the Predator's view. This was quite a technical feat, since the Predator was moving and its angle of view was constantly changing, yet those views had to be electronically aligned and registered with the stored imagery in less than one-thirtieth of a second (to match the frame rate of video recording).

In principle, the targeting step could have been hotwired to precision guided weapons. "We weren't actually doing that in Allied Force," Hansen notes. "We were just telling targeting officers exactly where Serbian targets were and then they would vector in planes to go strike the targets." That way the human decision makers could pre-empt flawed machine-made decisions. According to the Defense Advanced Research Projects Agency, TIGER technology was used extensively in the final three weeks of the Kosovo operation, during which "80 to 90 percent of the mobile targets were hit."

So far, real-time video manipulation has been within the grasp only of technologically sophisticated organizations such as TV networks and the military. But developers of the technology say it's becoming simple and cheap enough to spread everywhere. And that has some observers wondering whether real-

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Fitting the images: A video of a ground scene (green region) is superimposed on a satellite image of the same area. The ability to perform such georegistration in real time helped aim munitions at Serb targets in Kosovo. (This image comes from a test of the system in Maryland.)

time video manipulation will erode public confidence in live television images, even when aired by news outlets. "Seeing may no longer be believing," says Norman Winarsky, corporate vice president for information technology at Sarnoff. "You may not know what to trust."

The Sublime to the Ridiculous

A CRUDE FORM OF VIDEO MANIPULATION ALREADY IS HAPPENING in the satellite imagery community. The weekly publication *Space News* reported earlier this year that the Indian government releases imagery from its remote-sensing satellites only after defense facilities have been "processed out." In this case, it's not real-time manipulation and it's up front, like a censor's black marker. But pixels are plastic. It is perfectly possible now to insert sets of pixels into satellite imagery data that interpreters would view as battalions of tanks, or war planes, or burial sites, or lines of refugees, or dead cows that activists claim are victims of a biotech accident.

A demo tape supplied by PVI bolsters the point in the prosaic setting of a suburban parking lot. The scene appears ordinary except for a disturbing feature: Amidst the SUVs and minivans are several parked tanks and one armored behemoth rolling incongruously along. Imagine a tape of virtual Pakistani tanks rolling over the border into India pitched to news outlets as authentic, and you get a feel for the kind of trouble that deceptive imagery could stir up.

Commercial suppliers of virtual insertion services are too focused on new marketing opportunities to worry much about geopolitics. They have their eyes on far more lucrative markets. Suddenly those large stretches of programming between commercials—the actual show, that is—become available for billions of dollars worth of primetime advertising. PVI's demo tape, for instance, includes a scene in which a Microsoft Windows box appears—virtually, of course—on the shelf of Frasier Crane's studio. This kind of product placement could become more and more important as new video recording technologies such as TiVo and RePlayTV give viewers more power to edit out commercials.

Dennis Wilkinson, a Porsche-driving, sports-loving marketing expert who became CEO of 10-year-old PVI about a year ago, couldn't be happier about that. Wilkinson's eyes gleam when he describes a (near) future in which virtual insertion technology pushes advertisements to the personalized extreme. Combined with data-mining services by which browsers' individual likes, dislikes and purchasing patterns can be relentlessly tracked and analyzed, virtual insertion opens up the ability to shunt personally targeted advertisements over phone lines or cables to Web users and TV viewers. Say you like Pepsi but your neighbor next door likes Coke and your neighbor across the street likes Seven- Up—the kind of data harvestable from supermarket checkout records. It will become possible to tailor the soft-drink image in the broadcast signal to reach each of you with your preferred brand.

Just 15 minutes up the road from PVI, Sarnoff's Winarsky is also glowing—not so much about capturing market share as about the transforming power of the technology. Sarnoff has a distinguished history in that regard; the company is the descendant of RCA Laboratories, which started innovating in television

PVI/SAN DIEGO PADRES

Ads everywhere: The oil company logo that seems plastered behind home plate in this Padres-Dodgers game (top) is a mirage—a product of video insertion technology that gives way to a radar-gun readout.

technology in the early 1940s and has given birth to a plethora of media technologies. The color TV picture tube, liquid crystal displays and high-definition TV all came, at least in part, from RCA qua Sarnoff, which has five technical Emmys in its lobby.

The ability to manipulate video data in real time, he says, has just as much potential as some of these forerunners. "Now that you can alter video in real time, you have changed the world," he says. That may sound inflated, but after looking at the Katarina Witt demo, Winarsky's talk of "changing the world" loses some of its air of hyperbole.

Deleting people or objects from live video, or inserting prerecorded people or objects into live scenes, is only the beginning of the deceptions becoming possible. Pretty much any piece of video that has ever been recorded is becoming clip art that producers can digitally sculpt into the story they want to tell, according to Eric Haseltine, senior vice president for R&D at Walt Disney Imagineering in Glendale, Calif. With additional video manipulation technologies, previously recorded actors can be made to say and do things they have never actually done or said. "You can have dead actors star again in entirely new movies," says Haseltine.

Contemporary shots featuring footage of dead performers have been around for several years. But the Hollywood illusioncraft that, for example, inserted John Wayne into a TV commercial required painstaking, frame-by-frame post-production work by skilled technicians. There's a big difference now, says Haseltine: "What used to take an hour [per video frame], now can be done in a sixtieth of a second." This dramatic speed-up

means that manipulation can be done in real time, on the fly, as a camera records or broadcasts. Not only can John Wayne, Fred Astaire or Saddam Hussein be virtually inserted into pre-produced ads, they could be inserted into, say, a live broadcast of *The Drew Carey Show*.

The combination of real-time, virtual insertion with existing and emerging post-production techniques opens up a world of manipulative opportunity. Consider Video Rewrite technology, which its developers at the Interval Corp. and the University of California, Berkeley first demonstrated publicly three years ago. With just a few minutes of video of someone talking, their system captures and stores a set of video snapshots of the way that a person's mouth-area looks and moves when saying different sets of sounds. Drawing from the resulting library of "visemes" makes it possible to depict the person seeming to say anything the producers dream up—including utterances that the subject wouldn't be caught dead saying.

In one test application, computer scientist Tim Bregler, now of Stanford University, and colleagues digitized two minutes of public-domain footage of President John F. Kennedy speaking during the Cuban missile crisis in 1962. Using the resulting viseme library, the researchers created "animations" of Kennedy's mouth saying things he never said, among them, "I never met Forrest Gump." With technology like this, near-future political activists conceivably will be able to orchestrate webcasts of their opponents saying things that might make Howard Stern sound like a mensch.

Haseltine believes video manipulation techniques will quickly be carried to their logical extreme: "I can predict with absolute certainty," he says, "that one person sitting at a computer will be able to write a script, design characters, do the lighting and wardrobe, do all of the acting and dialog, and post production, distribute it on a broadband network, do all of this on a laptop—and viewers won't know the difference."

The End of Authenticity

SO FAR, THE WIDELY WITNESSED APPLICATIONS OF REAL-TIME video manipulation have been in benign arenas like sports and entertainment. Already last year, however, the technology began diffusing beyond these venues into applications that raised eyebrows. Last fall, for instance, CBS hired PVI to virtually insert the network's familiar logo all over New York City—on buildings, billboards, fountains and other places—during broadcasts of the network's *The Early Show*. *The New York Times* ran a front-page story in January raising questions about the journalistic ethics of altering the appearance of what is really there.

The combination of real-time virtual insertion, cyber-puppeteering, video rewriting and other video manipulation technologies with a mass-media infrastructure that instantly delivers news video worldwide has some analysts worried. "Imagine you are the government of a hypothetical country that wants more international financial assistance," says George Washington University's Livingston. "You might send video of a remote area with people starving to death and it may never have happened," he says.

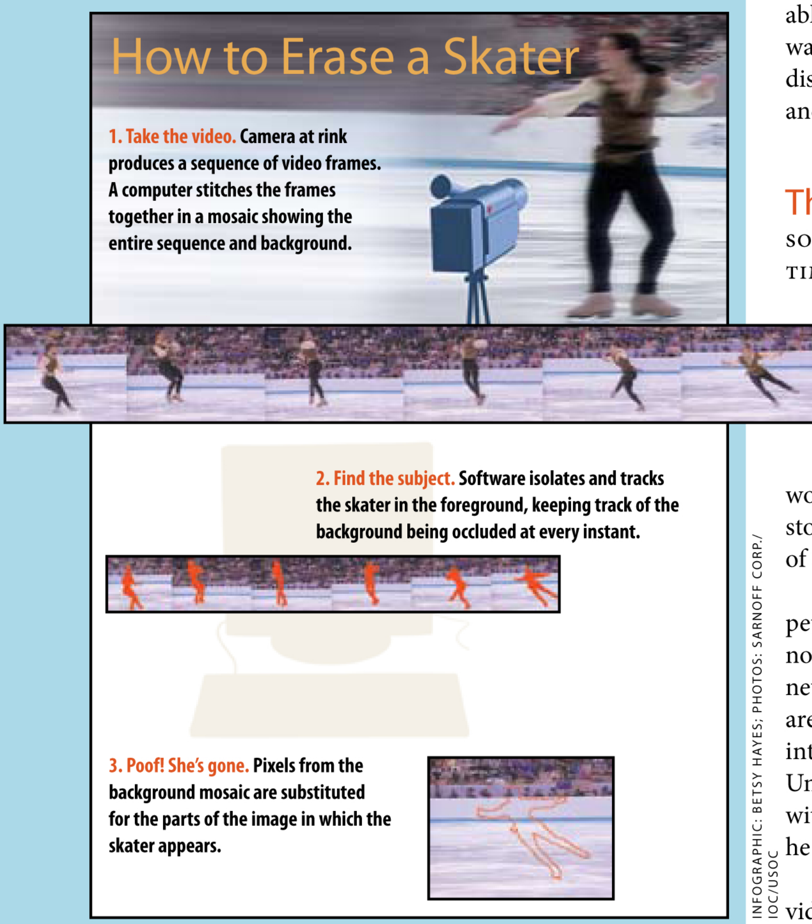
Haseltine agrees. "I'm amazed that we have not seen phony video," he says, before backpedaling a bit: "Maybe we have. Who

Vanishing Act

The procedure for offing people from a live video stream goes something like this. The first step is to align successive video frames, using fast computational techniques that detect and reorient patterns of pixels in successive frames. The computer stitches together the sequence of aligned frames into a mosaic that is constantly rebuilt as the computer receives new frames. In the case of skater Katarina Witt, the mosaics store information about what is behind her as she moves. While this is going on, fast frame-to-frame comparisons based on a Sarnoff-grown computational technique called "pyramid processing" enable the system to isolate and track objects moving in the foreground.

The key to pyramid processing is the succession of lower resolution versions of each frame it produces. Rather than having to compare full sets of pixels to detect frame-to-frame differences, such as Witt moving a few inches on the ice, the computer can rely on the reduced pixel sets. That greatly simplifies calculations, such as ones that track patterns of pixels that travel together through sequences of frames.

To erase Witt, the system summons the piece of the mosaicked background and inserts those pixels wherever the foreground pixel patterns change. By detecting which sets of pixels move with respect to one another and which sets remain relatively fixed, pyramid processing computers can track moving objects against stationary backgrounds. Since these calculations are doable in less than the thirtieth of a second between frames, there's time to replace moving foreground pixels with background pixels. Do that and you can make a skater—or anything else—vanish.



INFOGRAPHIC: BETSY HAYES; PHOTOS: SARNOFF CORP./IOC/USOC

PVI/MTV

Have a ball: The folks attending MTV's Ball2K never saw the wall-sized product promotions that were inserted into the video that aired in April.

would know?"

It's just the sort of scenario played out in the 1998 movie *Wag the Dog*, in which top presidential aides conspire with a Hollywood producer to televise a virtually crafted war between the United States and Albania to deflect attention from a budding Presidential scandal. Haseltine and others wonder when reality will imitate art imitating reality.

The importance of the issue will only intensify as the technology becomes more accessible. What now typically requires an $80,000 box of electronics the size of a small refrigerator should soon be doable with a palm-sized card (and ultimately a single chip) that fits inside a commercial video recorder, according to Winarsky. "This will be available to people in Circuit City," he says. Consumer gear for virtual video insertion is likely to require a camcorder with a specialized image-processing card or chip. This hardware will take signals from the camera's electronic image sensors and convert them into a form that can be analyzed and manipulated in a computer using appropriate software—much as photo editors at newspapers use Adobe Photoshop and other programs to "clean up" digital image files. A home user might, for instance, insert absent family members into the latest reunion tape or remove strangers they would prefer not to be in the scene—bringing Soviet-style historical revisions right into the family den.

Combine the potential erosion of faith in video authenticity with the so-called "CNN effect" and the stage is set for deception to move the world in new ways. Livingston describes the CNN effect as the ability of mass media to go beyond merely reporting what is happening to actually influencing decision-makers as they consider military, international assistance and other national and international issues. "The CNN effect is real," says James Currie, professor of political science at the National Defense University at Fort McNair in Washington. "Every office you go into at the Pentagon has CNN on." And that means, he says, that a government, terrorist or advocacy group could set geopolitical events in motion on the strength of a few hours' worth of credibility achieved by distributing a snippet of well-doctored video.

With experience as an army reservist, as a staffer with a top-secret clearance on the Senate's Intelligence Committee, and as a legislative liaison for the Secretary of the Army, Currie has seen governmental decision-making and politicking up close. He is convinced that real-time video manipulation will be, or already is, in the hands of the military and intelligence communities. And while he has no evidence yet that any government or nongovernment organization has deployed video manipulation techniques, real-time or not, for political or military purposes, he has no problem conjuring up disinformation scenarios. For example, he says, consider the impact of a fabricated video that seemed to show Saddam Hussein "pouring himself a Scotch and taking a big drink of it. You could run it on Middle Eastern television and it would totally undermine his credibility with Islamic audiences."

For all the heavy breathing, however, some experts remain unconvinced that real-time video manipulation poses a real threat, no matter how good the technology gets. John Pike, an analyst of the intelligence community for the Federation of American Scientists in Washington, D.C., says the credibility risks are simply too great for governments or serious organizations to get caught attempting to spoof the public. And for the organizations that would be willing to risk it, says Pike, the news folks—knowing just what the technology can do—will become increasingly vigilant.

"If some human rights organization popped up at CNN with some video, particularly an organization they were not familiar with, I would think that [CNN] would consider that radioactive," says Pike. Same goes for nongovernmental organizations (NGOs). "No responsible director of an established organization would authorize such a thing. And they would fire on the spot anyone caught doing it. The stock-in-trade of NGO policy organizations is that 'we tell the truth.'"

A government, terrorist or advocacy group could set geopolitical events in motion with a snippet of well-doctored video.

Even cool heads like Pike, however, concede that the media's fortress of skepticism has an Achilles heel: the Internet. "The issue is not so much your ability to get fake video on CNN, but to get it online," he says. That's because so much Internet content is unfiltered. "This could play into the phenomenon in the news production process where you would not replicate the original report, but you might report that it was reported," says Pike. And that could cascade into a CNN effect. "These are undoubtedly experiments that will be done," Pike says.

The trouble is, says Livingston, it may only take a few such experiments to forever make people question the authenticity of video. That could have enormous repercussions for military, intelligence and news operations. An ironic sociological consequence might emerge: a return to heavier reliance on unmediated face-to-face communication. In the meantime, though, there will undoubtedly be some interesting twists and turns as pixels become ever more plastic. ◊

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Eprise **$69 million** Initial Public Offering March 2000[2]	fairmarket **$98 million** Initial Public Offering March 2000[2]	Infineon technologies **€6 billion** Initial Public Offering March 2000[3]	Maker Communications, Inc. **$1.2 billion** Has been acquired by Conexant Systems, Inc. March 2000[2]	register.com **$138 million** Initial Public Offering March 2000[2]
yesmail.com **$721 million** Has been acquired by CMGI, Inc. March 2000[2]	Bluestone Software **$308 million** Follow-On Offering February 2000[2]	Broadbase **$318 million** Has acquired Rubric, Inc. February 2000[2]	c|net **$736 million** Has acquired mySimon Inc. February 2000[2]	e-centives **$24 million** Private Placement February 2000[2]
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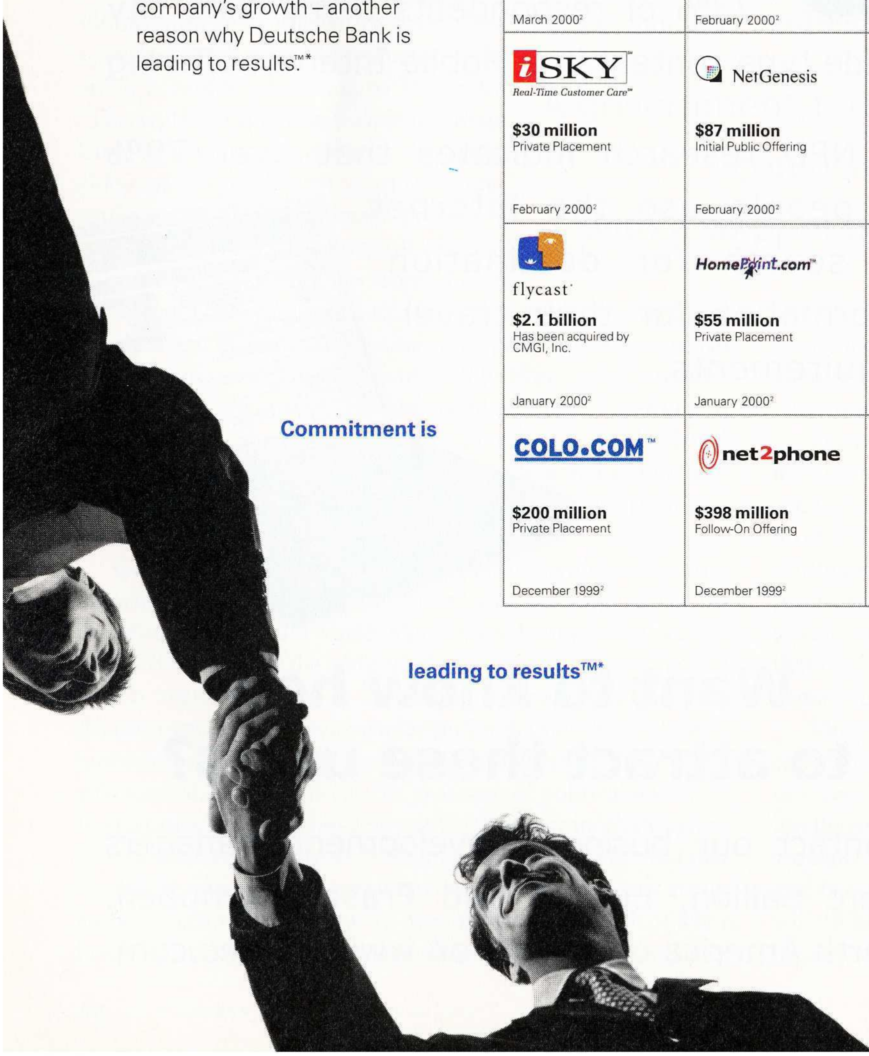
flycast **$2.1 billion** Has been acquired by CMGI, Inc. January 2000[2]	HomePoint.com **$55 million** Private Placement January 2000[2]	OpenPort technology **$25 million** Private Placement January 2000[2]	Pacific Century CyberWorks Limited **$129 million** Has invested in Softnet Systems, Inc. January 2000[2]	CollegeClub.com **$40 million** Private Placement December 1999[2]
COLO.COM **$200 million** Private Placement December 1999[2]	net2phone **$398 million** Follow-On Offering December 1999[2]	onDisplay **$113 million** Initial Public Offering December 1999[2]	hotjobs.com **$122 million** Follow-On Offering November 1999[2]	NBC **$4.2 billion** NBC has combined certain of its Internet assets with Xoom.com, Inc. and SNAP! LLC to form NBC Internet, Inc. November 1999[2]



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FreeShop.com **$44 million** Initial Public Offering September 1999[2]	luminant **$97 million** Initial Public Offering September 1999[2]	STERLING SOFTWARE **$179 million** Has acquired Information Advantage, Inc. September 1999[2]	trintech **$77 million** Initial Public Offering on Neuer Markt and Nasdaq September 1999[2,4]	yesmail.com **$37 million** Initial Public Offering September 1999[2]	AVEX **$289 million** Has been acquired by Benchmark Electronics, Inc. August 1999[2]	hotjobs.com **$27 million** Initial Public Offering August 1999[2]
NetScout. **$38 million** Initial Public Offering August 1999[2]	NorthChurch Communications **$182 million** Has been acquired by Newbridge Networks Corporation August 1999[2]	tellabs **$537 million** Has acquired NetCore Systems, Inc. August 1999[2]	TELOGY NETWORKS **$670 million** Has been acquired by Texas Instruments Incorporated August 1999[2]	wink. **$87 million** Initial Public Offering August 1999[2]	JDS Uniphase **$879 million** Follow-On Offering July 1999[2]	Mosaix **$202 million** Has been acquired by Lucent Technologies Inc. July 1999[2]
net2phone **$93 million** Initial Public Offering July 1999[2]	BigCharts **$166 million** Has been acquired by MarketWatch.com, Inc. June 1999[2]	DITECH **$38 million** Initial Public Offering June 1999[2]	EXCHANGE APPLICATIONS **$76 million** Follow-On Offering June 1999[2]	National Discount Brokers | ndb.com **$99 million** Follow-On Offering June 1999[2]	uniphase **$3.3 billion** Has merged with JDS FITEL Inc. June 1999[2]	flycast **$80 million** Initial Public Offering May 1999[1]
NETObjects **$72 million** Initial Public Offering May 1999[1]	Private Business **$40 million** Initial Public Offering May 1999[1]	iTurf **$106 million** Initial Public Offering April 1999[1]	PROXICOM **$67 million** Initial Public Offering April 1999[1]	sage **$130 million** Has acquired Tetra plc April 1999[4]	SoftNet Systems, Inc. **$152 million** Follow-On Offering April 1999[1]	asc Automated Securities Clearance Ltd. **$286 million** Has been acquired by SunGard Data Systems Inc. March 1999[1]
CDNOW **$264 million** Merger with N2K Inc. March 1999[1]	killer app **$49 million** Has been acquired by CNET, Inc. March 1999[1]	OneMain.com your hometown internet **$215 million** Initial Public Offering March 1999[1]	POWERWAVE TECHNOLOGIES **$62 million** Follow-On Offering March 1999[1]	sage **$145 million** Has acquired Peachtree Software, Inc. February 1999[4]	Hiway Technologies **$288 million** Has been acquired by Verio Inc. January 1999[1]	MarketWatch.com **$54 million** Initial Public Offering January 1999[1]

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The Real E-books

BY STEVE DITLEA

Forget those single-purpose e-book readers. The future of electronic publishing lies in files you can download to, view on and print out from the computer you already own.

It took a contemporary master of macabre thrillers to awaken the media and public to the existence of e-books. This spring, with great fanfare, Simon & Schuster brought out a novella by Stephen King called *Riding the Bullet*—the first work by a best-selling author released exclusively for electronic publication, to be read only on computerized screens, not paper. King's stunt made headlines and magazine covers, and the tsunami of demand for downloads of this e-book crashed Web sites and traditional publishing assumptions.

But the future of e-books may have less to do with Stephen King than with Eric Rowe and other less well-known authors. Rowe is a British potter who lives in the South of France, drawn there by the region's clays and minerals, which have been mined for stoneware since Roman times. To help ceramists in other areas unearth their own raw materials, he wrote *A Potter's Geology*. But he couldn't find a book publisher in England for his manuscript. This was just too specialized a topic for a publisher in any one country. Still, Rowe was certain that there would be interest in his book from potters everywhere.

PHOTO-ILLUSTRATION BY STUART BRADFORD

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Half a world away, in Medicine Hat, Alberta, Tony Hansen read about *A Potter's Geology* from a posting by Rowe in a ceramists' online discussion group. Hansen owns Digitalfire, a company specializing in software for calculations in ceramic chemistry. Hansen offered to publish Rowe's book electronically, selling the text on the Web as digital files in the Portable Document Format (PDF). PDF files are displayable on any Windows, DOS, Mac or Unix computer screen (and easily printed out) using the Acrobat reader software, downloadable free from Adobe Systems.

"I said I'd rather have my manuscript printed first," Rowe recalls. But Hansen won him over by pointing out that e-publication would produce immediate worldwide distribution. Now the book can be downloaded from the Web and viewed on any personal computer. Readers of the e-book can search the entire book and zoom in on high-resolution photos—even contact the author via an online hyperlink. The economics look good too: E-books require no printing, binding, inventory or shipping costs, allowing these savings to be passed on to the author in the form of higher royalties. *A Potter's Geology* has sold only a few dozen copies, but Rowe is optimistic: "It won't be something that sells fast, but over a long time. It's not a subject that will go out of date. Even so, in digital format it's easy to update or improve."

Thanks to Digitalfire and other budding digital publishing enterprises, authors like Rowe are being empowered to write about esoteric, highly personal topics and still find a worldwide audience—transcending the antiquated economics of shipping ink on wood pulp and bypassing the gatekeepers to traditional publishing. Just a little searching on the Web finds a growing e-book industry: more than 150 e-book-only publishers, e-only bookstores, e-book trade publications online, even e-book best-seller lists. The new e-publishers are testing a variety of business models for digital book distribution, while opening the way for a broader range of authors and works to be published on old-fashioned bound paper.

For people accustomed to reading text on a computer for hours at a time, e-book screen clarity is a nonissue.

The great wonder is that this hasn't happened any sooner. The first digital books date back to 1971 when Michael Hart was given a virtually unlimited account of computer time on the mainframe at the Materials Research Lab at the University of Illinois and decided that widely disseminating the contents of libraries was the greatest value computers could create. He typed in the text of the Declaration of Independence and so began Project Gutenberg, which now includes more than 2000 classic works online, all free. To date, these are all plain text files—lacking the typeset-quality formatting that makes books eminently readable, somewhat compromising the reading experience. "When we started," Hart recalls, "there was *only* uppercase—how about *that* for a compromise?" Because Project Gutenberg's books were no longer under copyright, the original e-books required no copy protection schemes. Hart explains: "We encourage everyone to repost our books in whatever formats they want. The most books to the most people—that's our only real goal."

In 1990, Voyager Co. introduced the first e-books meant to be read on personal computers. But these diskette-borne works, including *Jurassic Park* and *Alice in Wonderland,* were never offered by other publishers. Meanwhile, attempts to publish books on CD-ROM proved a dead end for all but encyclopedia and database publishers. The advent of the Web brought both opportunity and distraction for e-books. As the first universal publishing medium, the Web could make e-books easily accessible, with its Hypertext Markup Language (HTML) even retaining some print-style formatting. But HTML's orientation toward short documents was hardly optimized for book-length texts.

In the last year or so, the term "e-book" has been appropriated by companies selling portable gadgets whose sole purpose is to display electronic texts (*see "Files or Gadgets?" p. 76*). At the moment the number of these dedicated e-book readers—about 20,000—is dwarfed by the 6 million Palm Pilots and other Palm OS devices in use, making this versatile hardware the handheld reader of choice. "Single-purpose devices like handheld readers are never going to have as big an installed base as general-purpose ones," insists Mark Reichelt, CEO of Peanut Press, the Maynard, Mass., company that pioneered commercial e-book publishing on the Palm Pilot.

Rubber and Glue

The most general-purpose hardware boxes of all are personal computers. Yet despite hundreds of millions of PCs in use around the world, only a few hundred thousand of their users have downloaded e-books. The slow start is partly due to the perception that an e-book doesn't fully replicate the book-reading experience. More importantly, the download culture—first evident with browser plug-ins, then with software upgrades and MP3 music files—has only taken hold recently with the non-geek public.

Ads by Microsoft would have us believe that what the e-book world has been waiting for is the company's Reader program, which will be given away with every new copy of Windows. Microsoft Reader features ClearType software that evens out type edges on the screen. The reality is, however, that ClearType is warmed-over technology that failed to save handheld Windows CE devices from oblivion. To people accustomed to reading text on a computer for hours at a time, e-book screen clarity is a nonissue. Microsoft Reader also provides copy protection for authors and booksellers. But while e-books rights management may be important to intellectual property holders, it could be a futile quest. Any PC-based copy protection scheme can be cracked, as happened within two days of Stephen King's first e-publication.

With more than 100 million Acrobat readers already downloaded onto computers, PDF is the de facto standard for e-book publication. PDF was specifically designed for preserving professional-quality documents across computer platforms and printers. And PDF technology offers a ready solution for those reluctant to read off a screen; simply print out the files. To counter Microsoft Reader, Adobe has recently beefed up its offerings with e-commerce encryption software called PDF Merchant, allowing rights to an electronic copy of a book to be assigned

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to a single computer. In addition, Adobe has challenged Microsoft's ClearType with screen-enhancement routines of its own, which it calls CoolType; the competing technologies are similar enough in performance to make screen clarity even less of a concern. This year PDF will face a worthy challenger in the e-book format battle, as a consortium of e-book hardware makers, traditional publishers, and Microsoft push the new Open eBook (OEB) standard.

The difference between OEB and PDF is like the child's rhyme that begins: "I'm rubber, you're glue." PDF is glue, locking in a book's formatting so it can be preserved intact across output devices; once created, it is not meant to be modified in any way. This can be a drawback if an author or publisher wants to access parts of the text for excerpting or reconfiguring for a customized e-book, or for sampling or sale in smaller increments than book length. OEB is rubber: It allows an e-book's content to be reformatted on the fly, using a markup language that is essentially an extension of HTML. OEB also makes it easy for dedicated reading devices to reformat text to fit their proprietary display configurations.

The first published spec for OEB addresses neither security nor e-commerce protocols, leaving it to individual vendors to come up with their own approaches. This omission raises the possibility that the proposed standard could splinter into a variety of incompatible implementations. Ultimately, both OEB *and* PDF could survive, with the rival formats used for different output stages of the same e-book—OEB in the intermediate stages of massaging editorial content, and PDF for final versions. (For all the flexibility of digital books, scholarship will probably demand that different editions of a work remain available in permanent form.)

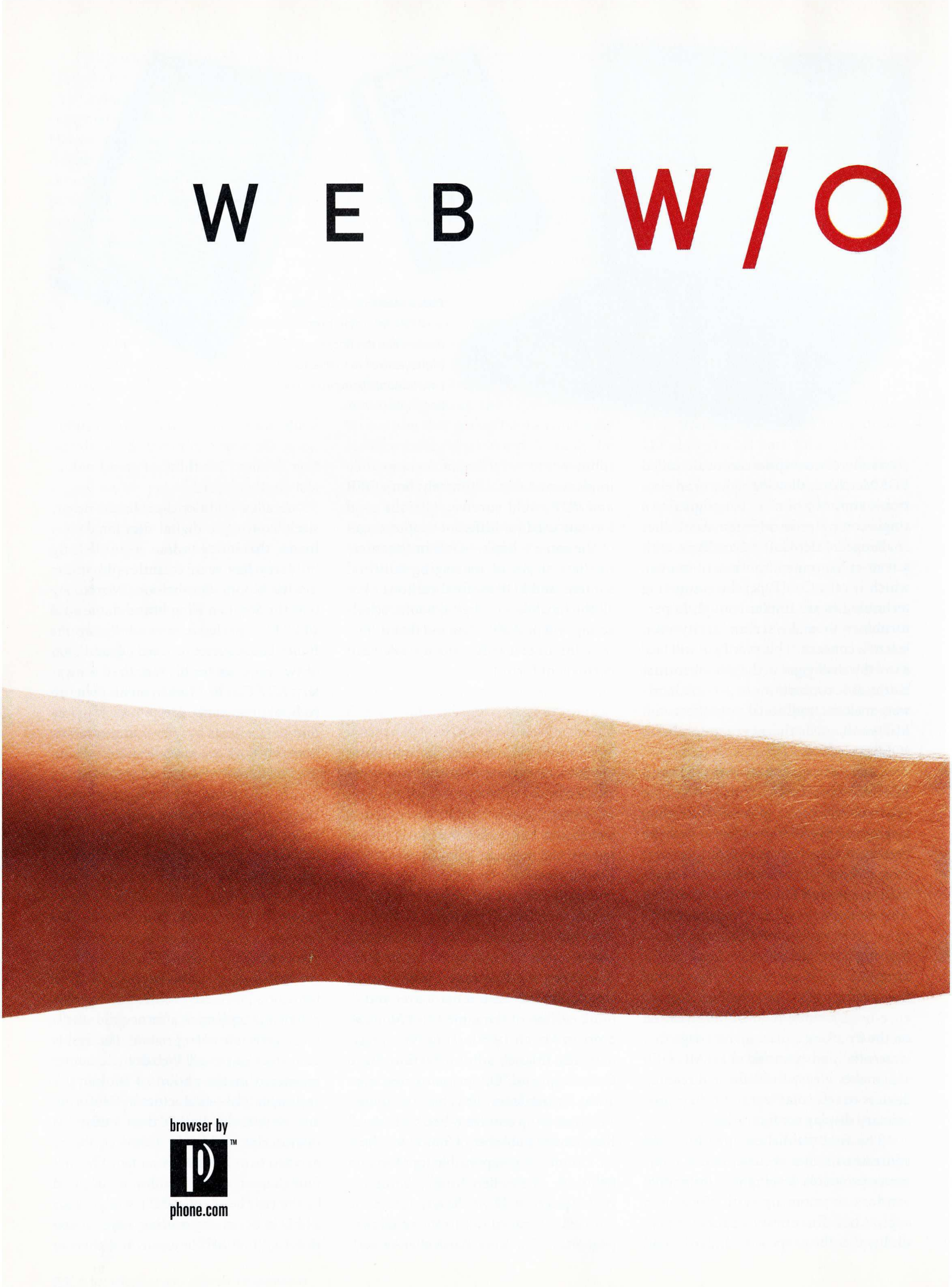
Rewriting Business Models

E-books are shaking up publishing business models that have remained unchanged since the days of Dickens, much as MP3 compression technology has rocked the music industry. For the moment, even the most forward-looking print publishers are pricing their initial e-book offerings almost identically with paper editions, as if there were no difference in their underlying atoms versus bits economics. At St. Martin's Press, the first major publisher to simultaneously issue a hardcover and e-book edition of the same title (*Monica's Story* in March 1999), senior vice president for finance administration Steve Cohen explains: "Our prices on new titles are at the hardcover level because there's a high start-up cost for e-book editions." Kate Tentler, publisher of Simon & Schuster Online, was responsible for Web distribution of Stephen King's *Riding the Bullet* (priced at $2.50, the 66 pages of the e-novella averaged out to the retail per-page cost of a King hardcover novel). Says Tentler, "We think of an e-book as just another book."

As a few traditional publishers defensively convert to digital files for downloads, the independent e-publishing industry has seen countless business models bloom. On the same March day that the Stephen King brand name sold 400,000 paperless copies of *Riding the Bullet*, Frank Weyer received a grand total of two requests for his serialized e-mystery, *MIT Can Be Murder*, on his own site (e-bookpress.com). Despite such paltry numbers, efforts by Weyer and other e-book authors are already undermining the influence of blockbuster-minded agents and trend-driven book editors. Weyer, for example, had sent the manuscript for his first murder mystery to 10 literary agents, all of whom declined to submit it to book publishers. "They said the mystery field is difficult for a newcomer," Weyer recalls. "But how do you become a published mystery author if you can't get published?"

Self-publishing on paper, a solution for some, seemed prohibitive for this patent and trademark attorney and small-scale Internet entrepreneur (he holds exclusive right to sell Web domain names registered in the nation of Moldova—ending in .md—to doctors in California and New York). Rather than letting his manuscript molder in a drawer, Weyer decided to publish it via e-mail. The first four chapters of the whodunnit, inspired by the year he spent at MIT studying for a PhD in ocean engineering, were offered first to 3,000 MIT alumni, and then to 15,000 names on other university alumni lists. He released the rest of the 210-page book in 12 monthly installments. Some 1,400 readers have downloaded the entire e-novel.

Weyer's novel-by-subscription might seem like an innovation made possible by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the digital era. In fact, it is a throwback to the early days of 19th-century book publishing, when books were sold by subscription before publication, to raise revenue to pay the printing costs up front. With no printing to worry about, the frictionless economy lets Weyer distribute his work for free. Now that he has successfully bypassed print publishers to get his words read, he has begun subscription-publishing the work of other writers. The first addition is *The Butcher's Cleaver*, a spy thriller by W. Patrick Lang. Soon Weyer plans to generate income by selling print-on-demand versions of both his and Lang's books. Nonetheless, he would like *MIT Can Be Murder* to be picked up by a mainstream publisher. "I just wanted to build word of mouth," he says of his e-book. "I would like to see it in as many forms as possible."

Giving away complete works to help an author build a following is still anathema to most traditional publishers, who must absorb the cost to produce, store and ship the physical books. But giving away paperless e-books is a no-brainer, following the time-tested freeware and shareware models in computer software. Independently published e-books may not be as polished or as slick as store-bought commercial offerings, but they can hold their own in user appreciation. And Frank Weyer's writing is certainly on par with that in much of today's mass-produced paperback fiction.

Traditional publishers' understandable fear that e-books may cannibalize sales of print editions seems to be overblown, at least judging from the experience of one of their more adventurous colleagues. Last September, veteran science-fiction publisher Jim Baen initiated what he calls eWebScriptions; for $10 a month, visitors to Baen.com may download quarter-of-a-book-sized installments of four titles about to appear in print. Even after receiving the full text in HTML, "more of our subscribers buy the finished book than don't buy it," says Baen. By March, the added promotion had already helped propel one of the earliest eWebScriptions titles, *Ashes of Victory* by David Weber, onto hardcover best-seller lists.

In addition to alternative marketing strategies, e-publishers can tap into income streams legally denied to traditional publishers. For instance, the U.S. Postal Service disallows low book-mailing rates for printed material that contains advertising. No such restriction inhibits the sales of ads for e-books. Bartleby.com, for example, offers free, ad-supported classics and reference works online. At BiblioBytes.com, books can be read on ad banner-sponsored Web pages, with some popular titles downloadable for a fee; authors get a cut of the ad revenue. Abroad, the alternatives are just as dramatic; in France, pioneer e-publisher Zero Hour is able to offer less-expensive editions of current books because digital files cannot be taxed as print books are.

Embracing the E

The power of e-books as a promotional medium has probably best been demonstrated by Melisse Shapiro, who writes under the nom de plume M.J. Rose. Her first novel, *Lip Service*, an erotically charged thriller, was rejected by a dozen book publishers for being too steamy for the chain bookstores. She opted to publish from her own Web site, offering digital downloads for $10 or photocopies of the manuscript for $20.

Even when the password for her e-book was stolen and posted online, resulting in 1,000 pirated downloads, she managed to receive 150 paid orders for e-books and 500 orders for photocopies. She invested in printing 3,000 copies to help create buzz; at one point, it was the 123rd best-selling title on Amazon.com. Following her online blitz, Doubleday Direct picked up *Lip Service* for its mail-order book clubs and soon after, Pocket Books signed up print rights in hardcover and paperback. Building on her success, Shapiro has become a leading advocate of e-books, with her frequent reports to Wired News online providing the most comprehensive ongoing coverage of e-publishing. "Everything in my life would be different if not for e-books," she says.

On the same day in March that Stephen King generated 400,000 orders, Leta Childers' comic romance e-novel, *The Best Laid Plans*, was downloaded 200 times from her publisher's Web site, DiskUspublishing.com. Childers is King's peer in one respect: Hers is the best-selling work released to date among digital-format-only publishers, according to the best-seller list compiled by eBook Connections. With some 20,000 copies of her e-book issued (at $3.50 for a downloaded copy, $6.50 on diskette), the rural South Dakota-based Childers has helped establish DiskUs Publishing of Albany, Ind., as one of the most successful digital-

Files or Gadgets?

The real e-books are specially formatted digital files of a printed book's content that can be displayed on, or printed out from, any garden-variety computer. Nevertheless, much of the e-book publicity of recent years has been drawn to single-purpose devices whose function is to display reading matter in a booklike fashion.

None of these devices has ever really caught on. It's not hard to see why, beginning with the handheld electronic dictionary that was introduced by Franklin Electronic Publishers in 1986, displaying a mere one line of text at a time. Five years later, Sony's Data Discman displayed disc-stored books on a roughly 8-centimeter screen—an improvement, but still too small for comfortable book reading.

By 1999, the hardcover-sized SoftBook Reader from SoftBook Press and the paperback-sized Rocket eBook from NuvoMedia attracted media attention to the current generation of e-book display gadgetry. While well designed, these dedicated devices are pricey: $200-$600. Another big drawback is the readers' proprietary file formats, requiring that additional versions of e-literature be made available for downloading. (Not everyone is down on these devices: *Technology Review* contributor Wade Roush liked the Rocket eBook he reviewed in these pages last November so much that he took a job with NuvoMedia, as an editor of its online e-book trade publication, eBookNet.com.)

In January 2000, both SoftBook Press and NuvoMedia were acquired by Gemstar International Group. Gemstar aims to relaunch versions of both readers, manufactured by Thomson Consumer Electronics, with expectations of selling about half a million units a year. If these gadgets succeed, you'll read all about it.

only publishers. In the still largely New York-based traditional publishing world, Childers says, "submission envelopes with Midwest return addresses are easy to ignore." Then in a familiar refrain for e-book authors, she adds: "I would love to be traditionally published."

DiskUs is a publisher in the traditional sense of having editors who help prepare manuscripts for publication. Other e-publishers disseminate authors' works for a fee, without exercising editorial control. Such "vanity presses" have long been the Rodney Dangerfields of publishing, but vanity e-publishers are proving attractive to mainstream book firms exploring new publishing paradigms. Following a recent investment by Random House, Xlibris.com now provides a no-fee, no-frills e-publishing package. Barnes & Noble is backing iUniverse.com, which offers new authors a basic $99 e-publishing service; it reserves free publication for authors submitting out-of-print works, a program originally developed with The Authors Guild.

For authors who've already been in print, one of the greatest benefits that e-books can offer is the resurrection of their old hard-to-find titles. As publishing companies have consolidated, worthy works have been relegated to the limbo of out-of-print. E-publishing provides an inexpensive way to restore the availability of these lapsed works. Among the most innovative of e-publishers, Alexandria Digital Literature has revived hundreds of out-of-print stories and poems, typically priced from 30 cents to $1.25. Buyers are asked to send in their ratings; when enough ratings accumulate, they can be compared to others' ratings and other reading recommendations are offered.

Also being revived are questions about traditional publishers' exclusivity over their authors' works. When Simon & Schuster made Stephen King's *Riding the Bullet* available through online booksellers and e-book hardware and software firms, one site was pointedly excluded: Fatbrain.com. Since last fall, Fatbrain has been posting works it brands as "eMatter": original fiction and nonfiction ranging from 10 to 100 pages (lengths that many people will be willing to print out). Subsequently designating the site for such pieces MightyWords.com, Fatbrain has targeted a segment of publishing that falls between magazines and books, where the modern economics of print have all but shut out a once-thriving sector of short stories and novellas. Simon & Schuster saw Fatbrain as a rival.

Digital downloads should become one more step on the convenience/cost continuum: hardcover to paperback to e-book.

Fatbrain's brief history shows how quickly e-book business plans and branding can change. A mere six months after launching the eMatter trademark and drawing attention to the similarly named Web site, Fatbrain decided to let its trademark lapse. "MightyWords was a name that could ring through to our professional audience, while eMatter is a generic term for the range of electronic documents we are publishing," explains Judy Kirkpatrick, executive vice president and general manager of MightyWords. Already the eMatter 10-to-100-page category encompasses many of e-book publishing's early milestones, including King's *Riding the Bullet*. Simon & Schuster may not like it, but Fatbrain's publication of an eMatter essay by science fiction author Arthur C. Clarke was the inspiration for King to test the digital publishing waters. Also fitting the eMatter designation: Eric Rowe's 91-page *A Potter's Geology*.

King and Rowe have something else in common: an abiding belief in the importance of traditional books. King has been widely quoted as stating: "I don't think anything will replace the printed word and the bound book. Not in my lifetime, at least." For Rowe, too, it's not a question of digital books supplanting analog ones. "For some kinds of book," he says, "the aesthetic pleasure of having the object in the hand will be difficult to replace."

It should come as no surprise that proponents of e-books are not out to eliminate paper publishing. After all, most e-books attempt to replicate traditional books' content and appearance. For the most part, e-books can be printed out with only minimal loss of information (primarily broken hypertext links). And for all their seeming differences, print and electronic publishers are putting out similar content. Eventually, digital downloads seem destined to become just one more format for readers, one more step on the convenience/cost continuum from hardcover to paperback to e-book.

At some point in the future, however, e-books and print are bound to diverge. Lurking amidst e-publishing today is the notion of multimedia books that seamlessly incorporate hypertext, sound and animation. A hypertext branching narrative in a novel or a history book, for instance, would be impossible to reproduce in a book.

A glimmer of tomorrow's multimedia books, or m-books, may be discerned in a dark-horse contender among e-publishing file formats called TK3. Introduced by Night Kitchen—a New York startup headed by Voyager Co. co-founder Bob Stein—TK3 is the basis for a sophisticated literary software environment. The Night Kitchen TK3 Reader offers the most booklike reading experience on a desktop or laptop computer screen—complete with highlighting, corner-folding bookmarks, even Post-it-like "stickie notes." And TK3's easy-to-use multimedia authoring tools are meant, according to Stein, "to empower a new generation of authors who want to express themselves in the new media." Using this hyperlink-sound-and-motion superset of traditional books to express themselves, such a new generation of authors would hasten Stein's prediction that "the locus of intellectual discourse will shift from the print medium to the electronic medium."

For now, the advent of e-books means not replacing print, but supplementing it—redefining publishing economics and opening the way for authors whose work has been kept from appearing between book covers. If e-books do nothing more, regardless of the success or lack thereof of new gadgetry to display them, this technology will have a profound effect on what we read and what we think. ◊

Join a discussion about e-book technology at www.techreview.com/forums.

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{How technology lets you experienc

Agility, as defined by Cor

By Cheryl Pilcher, Co

Taking one of the world's premier sports cars to the next level of performance is not an easy task, or one we take lightly. Corvette® owners are

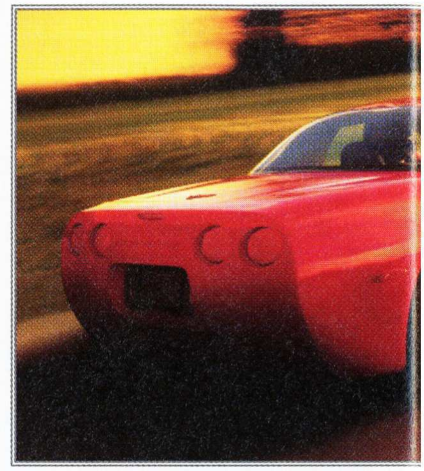
{ Corvette coupe features include an easily removable one-piece top with magnesium frame. }

enthusiasts, and when we consider enhancing their driving experience, we do so with the knowledge that we must do *exactly* that. Esoteric engineering exercises that result in little or no benefit to the driver have no place in the Corvette mission.

What Is Active Handling? Corvette Active Handling is the logical next step in the evolution of enhanced chassis control systems like ABS brakes and Traction Control. The available Active Handling System activates when there is a significant difference between how the driver *intends* for the car to corner and how the car is *actually* cornering. Working with the ABS, it automatically applies any of the four brakes to help actively control the situation.

The Tough Part, Really, Is the Human Part. The thing we've learned about Corvette drivers is that it's not only the car's performance that they love, but it's being *in control* too. Active Handling had to be developed to enhance the driver's control without being intrusive. Before we could create the algorithms for the software, we had to drive thousands and thousands of miles, *anticipating* virtually every driving situation imaginable, not only on dry roads, but on wet and snowy roads, too. This is what we mean by the human part. Computers are great. But you have to collect accurate data and set up the computers properly to deliver the kind of driving experience that a Corvette driver demands.

Agility and Subtlety for the Real World. The available Corvette Active Handling System offers amazing agility for the kinds of situations you encounter in real-world driving. Imagine a sudden lane change on a wet road surface to avoid an unexpected hazard — like a huge pothole. Let's say you turn the



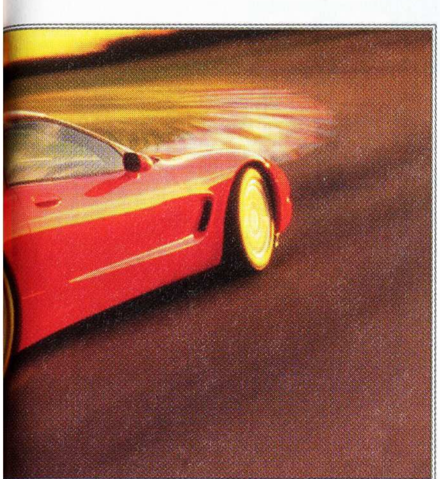
{ Performance for performance sake, the hardto

wheel sharply to the left to avoid it. This input, combined with the low-traction surface, could exceed the limits of traction available to the fro wheels, causing "understeer," allowing the car t "plow" straight ahead. In this situation, Corvett

Corvette to its fullest capability.}

ette with Active Handling.

ette Engineering Group



is the ultimate Corvette for sports car purists. }

Active Handling will work to help correct the car's understeer condition by automatically applying the left rear brake, coaxing the car to the left. Of course, an aftereffect of this maneuver could be that the tail of the car may actually start to swing out the other way in a classic "oversteer" condition. The subtlety of Corvette with Active Handling is that it responds to this natural overreaction and brings the rear of the car back in line. Yet its operation is so sophisticated, the chances are good that you will never sense the system's activation.

A Note of Caution: The overall effectiveness of the Corvette Active Handling System is directly related to available tire traction and the aggressiveness of a given maneuver. Active Handling is designed to use existing traction to assist the driver — *but it cannot overcome the laws of physics. Please drive responsibly.*

Competitive Driving Mode for the Track. The Corvette Active Handling System is the first of its type in the world to offer dual-mode operation. You can engage a *competitive driving* mode for autocross, gymkhana or other on-track activities. In this mode, Active Handling remains fully functional—

{ The C5 was designed from day one to be a world-class sports car that's also a convertible. }

while the traction control is disabled, allowing for some wheelspin and oversteer, so more experienced drivers can enjoy the dynamic capabilities of Corvette on the track.

This Is a Corvette to Love. You have to drive the 2000 Corvette with available Active Handling to appreciate how great it really is. We set out to design the ultimate Vette for enthusiasts and I think we knocked it out of the park. We love driving it. And we think you'll love it too.

The Only Sports Car That Matters.

CORVETTE


ivory tower
overhead
tradition

FROM THE Ivory Tower TO THE Bottom Line

IN THE 1990s U.S. COMPANIES CUT COSTS, JETTISONED MARGINAL EFFORTS, BOLSTERED INTERNAL COOPERATION AND FORMED STRATEGIC ALLIANCES. HOLD ON TO YOUR HATS—UNIVERSITIES ARE SET TO DO THE SAME.

BY ROBERT BUDERI

Cornell University president emeritus Frank Rhodes chuckles recalling the incident. It was back around 1986. Ronald Reagan's acting science advisor John McTague had toured the campus and come away extremely impressed with Cornell's scientific investigations. Afterward, at a symposium attended by several hundred faculty and guests, he joked that he was going to devote the entire $67 billion-plus federal research-and-development budget solely to Cornell. That was when the Nobel laureate physicist Kenneth Wilson called out: "Not enough."

Although tongue-in-cheek, Wilson's quip was telling. For reasons that extend from rising faculty salaries to the struggle to modernize curricula and facilities, the nation's top universities have long been addicted to growth—a major factor in driving tuition rates consistently above the inflation rate. Unable to curb their habit, even in the face of flattening federal and state support, they have turned to alternative financing methods that include inking more deals with industry, licensing inventions and other novel profit-making ventures.

But it's getting harder to keep the growth juggernaut rolling—and far-sighted advisors have warned for years that universities will one day find themselves spread too thin. Now, a day of reckoning seems at hand. The issue goes beyond just holding down costs. A growing body of the nation's academic leaders also feel that perpetuating the old ways of teaching and research—especially via isolated academic disciplines—could hinder learning and discovery. They're pressing to dismantle outdated departments to focus better on core strengths and break down barriers between remaining departments to form more interdisciplinary majors and research centers—addressing what Stanford chemist and former National Science Board chairman Richard Zare terms "the realization that many breakthroughs require clever combinations of the methods, approaches and tools of different disciplines."

ILLUSTRATIONS BY POLLY BECKER

These plans are strikingly reminiscent of the retooling many U.S. corporations undertook to spark innovation in the 1990s. Wielding terms like "selective excellence," university presidents, provosts, deans and professors are engineering a major change in the way schools operate. Rhodes calls this overhaul an escape from the "Harvardization of the campus." U.S. institutions of higher learning have for too long followed Harvard's style of trying to excel at everything—liberal arts, library collections, science and all the rest—he said at a Cornell symposium last December. But given today's rapid accumulation of information in an ever-expanding array of disciplines, that is impossible now, even for Harvard. Proclaimed Rhodes, "The next century, I believe, will belong to those that are successful in de-Harvardizing."

No Pain, No Gain

THE METAMORPHOSIS IN PROGRESS promises to be gut-wrenching for traditionally staid campuses. Still, the historical record suggests that the university will survive. A little more than a century ago, the United States saw the emergence of polytechnic-type schools that walked hand in hand with industry by offering programs in the application of electric power and chemistry to business processes. But mirroring the country's blossoming as an economic and cultural power, most schools evolved into broad-based institutions with many departments. A new, more academic model of the university arose, with campuses devoted to acquiring and dispensing "pure" knowledge without regard to direct commercial gains.

This ivory tower expansion also saw the embrace of science. By the 1930s, America's scientists were vaulting to the world's highest levels. Their ranks swelled after World War II, when the success of science in everything from the atomic bomb to penicillin prompted the government to pour money into academic research—resulting in a dramatic expansion of research universities. It's the end of this era that is shaking up campuses today. Moreover, just as social and economic changes drove the push to ivory tower education, today's revision is taking place in the context of a shift from a largely insular industrial economy to a global, knowledge-based or "conceptual" economy.

The need to adapt to a changing world forms the essence of "de-Harvardization." But Rhodes and others also call it the "corporatization" of the campus, in part because it mirrors many changes recently undergone at companies such as IBM, General Motors and 3M, whose own golden age ended in the 1970s and 1980s. Indeed, facing fierce international competition, all realigned their structure and strategic direction. They cut costs, shed operations not related to core technologies, bolstered internal cooperation and formed new alliances—all strategies now being adopted by university leaders.

Money, of course, drives much of the university's transformation, just as it did for corporations. In recent years, schools have somewhat offset the slowdown in federal and state support for research by cutting administrative overhead. But other forces, such as the need to keep professors' salaries competitive and the hard-to-dispute conviction that more research *does* produce more knowledge, combined to make more substantial cuts impossible—and keep tuitions rising.

Inexorably, the need for new funding sources drove universities to industry. The bonds between the two had loosened in science's golden age. But the new university need, coupled with corporations' desire to offset their own slimmed-down research programs through better access to academic science, changed all that. Industry's contributions to academe are approaching \$2 billion a year—some 10 times 1979 rates. Meanwhile, a series of legislative changes encouraged universities to become patent and spinoff machines *(see "The* TR *University Research Scorecard," p. 88)*.

But even these monetary measures and countermeasures could not stem the pressures on the "Harvard" model. No one understands this better than the veterans of the corporate wars. As former IBM vice president for science and technology John Armstrong noted in a 1996 talk, "There is no leading university of my acquaintance which does not have faculty deadwood, outdated programs and a few departments whose disappearance would raise the overall quality of the institution." Although deadwood had been tolerated historically to protect campus stability, Armstrong argued that things would have to change "if the quality of good programs is not to be eroded because resources are being wasted on mediocre programs." More than a few universities heard this message—or similar ones—and moved to create a leaner, meaner campus.

Slimmed-Down and Well-Connected

THE LEADER ON THIS FRONT might well be venerable Yale, where in 1996 president Richard Levin unveiled the principle of "selective excellence." Levin explained that "no university...has the resources to be the best in the world in every area of study." Therefore, he explained, "our programs should be shaped more by an aspiration to excellence than a compulsion to comprehensiveness."

Talk about taking on the status quo. Yale was about to shift its historically much broader focus to its core—Levin called them "distinctive"—strengths. That meant protecting first of all its noted arts and humanities programs. The biological sciences and medical school, accounting for some 40 percent of Yale's revenues, were also untouchable. For other fields, though, it was often a matter of picking specialties where a few key faculty hires could make Yale a world leader—and letting others slip as tenured faculty retired. As deputy provost Charles Long explains: "The good get more and the not so good get less."

Yale's approach to engineering might best illustrate its new climate. Ever since its engineering school was disbanded in 1966—in favor of a scaled-down faculty of engineering—Yale has struggled to get its program back on the world map. Selective excellence could give those efforts a boost.

Seeing no way to compete on the scale of powerhouses like MIT or Stanford, Yale has already moved to strengthen the most successful areas—including microelectronics, imaging technology and acoustics—while adding efforts in biomedical and environmental engineering. It then worked to strengthen these programs further by joining forces with other disciplines: Witness its proposal to the National Science Foundation to create an engineering research center that would host 22 tenured faculty members from 11 departments at Yale and the University of Connecticut.

D. Allan Bromley, who spearheaded many of these changes before stepping down as engineering dean last June 30, says his organization now has teaching or

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research collaborations "with just about every one" of Yale's schools and departments. "This is vitally important," Bromley adds, "because we would not have a chance to hire faculty members to cover all these topics if we had to do it department by department, or school by school." In this way, he notes, while Yale may not match bigger programs in turning out bench engineers, it is preparing students to better understand how technology will be developed in the future.

Other schools are taking similar action. Ohio State University recently hired renowned Berkeley chemist C. Bradley Moore as vice president for research—a position that will help him drive OSU's own version of selective excellence. Moore describes his challenge as addressing the heightened need to focus research, while extending excellence to more disciplines. "An important aspect of most of these new horizons is that they are fundamentally multidisciplinary—so if you don't have the strength in most of the disciplines you need, and the ability to build collaborations in the areas where you don't have the strength, you're out of luck," he says.

Even before Moore's official arrival, OSU's College of Food, Agricultural and Environmental Sciences was leading the way to this goal—in part through its six-year-old Project Reinvent. Backed by a $1.5 million Kellogg Foundation grant, the college canvassed some 650 faculty, staff and constituents before revealing four prime elements of future success. Two centered around the traditional focus on agricultural production and economic viability. But the remaining pair expanded the program emphasis to address issues of environmental and social responsibility.

These four principles not only guide evaluations of existing efforts but the creation of new programs as well. What's more, Project Reinvent was launched against the backdrop of a fundamental reorganization that saw the number of academic programs cut from 11 to eight—and much of the rest reoriented. The college launched new partnerships in medicine and cancer research while continuing others in areas such as veterinary medicine, biology, engineering and human ecology. It even teamed with the college of arts and sciences to bring cultural events—music, plays, readings—to rural communities. A few years ago, says dean Bob Moser, the school mustered only a handful of interdisciplinary teams. Today, there are more than 40. "I'm saying three years from now, the majority of what we do will be in a team environment."

That same outcome isn't far off target for Stanford University, whose sights are turning increasingly to multidisciplinary research. Few efforts, though, approach the scope of Bio-X, an initiative that blends biology, chemistry, physics, engineering and medicine to explore basic and applied biomedicine and bioengineering. The project, bankrolled by $100 million from Netscape founder Jim Clark, involves the creation of a new facility that will be staffed by some 50 faculty drawn from Stanford's engineering, medical and humanities and sciences schools. Richard Zare, a project steering committee member, says that although interdisciplinary research has been around for decades, the growing understanding that technological innovation requires diverse skills makes it vital to unite previously individualistic departments. In the case of Bio-X, he says, immunologists and surgeons can team up to overcome organ transplant rejections, or lasers can be combined with the biology of muscle motion to explore molecular motors.

U.S. University, Inc.

Many worry that the new corporate attitude threatens the very fabric of the university. "The danger is that you unwittingly lose sight of the ultimate aim of education and that you confuse commercialization with the deeper purposes of higher learning," warns Stanley Ikenberry, president of the American Council on Education.

Ikenberry says schools are therefore engaged in "a constant yin-yang struggle between trying to focus and prioritize on the one hand and on the other trying to maintain some idealized vision of the classical university." Not so long ago, corporations gave unrestricted money to colleges to cultivate good will. Now, they mainly back projects that have direct commercial payoffs. Sponsors typically get first rights to the fruits of research they support, and scientists must often delay publishing their results to give corporations a leg up on commercialization.

All these concerns merit constant vigilance. But when Rhodes and other educational authorities insist the "de-Harvardization" and "corporatization" of the American campus is inevitable—and only just beginning—it's best to take note. After all, no school *can* do it all. And to thrive in the current climate virtually requires a corporate-like attitude of watching the bottom line, bringing down institutional and departmental barriers to innovation—and wheeling and dealing.

> The Harvard model of a university that tries to be all things to all people doesn't jibe with today's competitive research environment.

Meanwhile, a host of university officials believe the potential rewards are vital to economic well-being. Frank Rhodes cites statistics that show that the alumni and faculty of MIT, long a leader among "corporate" campuses, have spawned some 4,000 companies that employ 1.1 million people and generate $230 billion in annual sales—a feat that as a stand-alone economy would rank it 23rd in the world, "between South Africa and Thailand." That's a strong argument for continuing on the current path. And, if revitalized firms such as Lucent or IBM are any model, anything that brings better focus and interdisciplinary teamwork to the campus will likely create a fresh spark of discovery, unleashing what Yale's Long terms "a powerful impact on scholarship, teaching and larger society."

Kenneth Wilson, the voice from the back of the room during McTague's talk at Cornell, won his Nobel Prize in 1982, at the height of the ivory tower era. Now at Ohio State, even he is an advocate of the new course. "You don't get things done by being an island unto yourself anymore," he says. "Each university has to have its own character now. Each can figure out a way to pick its areas of strength, and then leverage those to partner with somebody else."

By the way, he adds, that budget for university research? Still not enough. ◊

THE *TR* University Research Scorecard

WE RANK THE TOP U.S. UNIVERSITIES IN THEIR QUEST FOR INTELLECTUAL PROPERTY, COMMERCIAL PARTNERS AND PROFITS.

BY REBECCA ZACKS

Long before Bob Dole abandoned his presidential dreams and became the unlikely spokesman for Viagra—a celebrated product of industrial research—he gave an even bigger lift to academic research. In 1980, Dole and fellow U.S. senator Birch Bayh sponsored the Bayh-Dole Act, legislation that gave blanket permission for universities to license and profit from the fruits of federally sponsored research—rights previously held by Uncle Sam.

The Bayh-Dole act turned out to be Viagra for campus innovation. Universities that would previously have let their intellectual property lie fallow began filing for—and getting—patents at unprecedented rates. Coupled with other legal, economic and political developments that also spur patenting and licensing, the result seems nothing less than a major boon to national economic growth. Behind big university patents such as Carnegie Mellon's Lycos Internet technology and the University of Minnesota's AIDS-fighting carbovir—along with a host of lesser technologies—campus inventions supported some 280,000 jobs and generated an estimated $33.5 billion in economic activity in 1998, the last year for which figures are available.

TR's University Research Scorecard takes you inside this increasingly vital part of the economy, analyzing academia's ever-increasing IP firepower using two separate rankings of top U.S. educational institutions. The first, based on data from CHI Research of Haddon Heights, N.J., assesses patenting prowess via a measure called "technological strength," which takes into account not only patent numbers but also patent quality *(see "Campus Patenting," p.89)*. The second, based on data from the Association of University Technology Managers (AUTM), lists the 25 universities with the highest licensing revenues *(see "Tech Transfer Riches," p.90)*. Since patents generally don't begin to generate license income until five to 10 years after a deal is signed, the two together not only show who's ahead in the race to capitalize on university inventions, but who is coming on strong for the future.

A glance at *TR*'s scorecard confirms that the race is being run at an increasing clip: Technological strength was up in 1999 for 44 of the top 50 schools; patent numbers were up for all but two. Not surprisingly, the biggest players dominate the patent numbers: The University of California system, MIT and Caltech have amassed war chests of intellectual property across a range of technologies from medicine to fiber optics.

But raw patenting numbers aren't the only significant factor when it comes to the money side of the equation, and some schools with relatively few patented inventions are reaping huge returns. Columbia, for example, ranks second in licensing income and makes nearly a quarter of its $260 million research investment back in royalties and fees, even though the school garnered only 34 patents per year on average from 1994 to 1998. Third-place Florida State University, meanwhile, rakes in an astounding 42 percent of its $112 million annual research budget through a mere 10 licenses or options deals.

The Florida State story illustrates a truth university licensing managers know all too well: All it really takes to win the financial game is one IP home run. The school's director of technology transfer, John Fraser, puts it bluntly: "Fundamentally, we're a one-horse operation, and that horse is called Taxol." The anti-cancer drug, which Florida State licensed exclusively to Bristol-Myers Squibb, earned the university some $45 million of its $46.6 million in licensing income in fiscal year 1998. The school could net more than $60 million on Taxol this year.

But while that likely makes Taxol the single biggest moneymaker of all active university patents, it's got a rival for the crown. In April, the University of Rochester won what may well turn out to be the greatest prize of all: patent rights that cover

Key

Technological Strength: The number of U.S. patents multiplied by the Current Impact Index (see below).
Number of Patents: The total number of U.S. patents awarded, excluding design and other special-case inventions.
Current Impact Index: A measure of how frequently an institution's patents for the previous five years are cited in the current year, relative to all patents in the U.S. system. A value of 1.0 indicates average citation frequency.

Data from CHI Research.

Campus Patenting

INSTITUTION*	TECHNOLOGICAL STRENGTH 1999/RANK	TECHNOLOGICAL STRENGTH 1994-1998†/RANK	NUMBER OF PATENTS 1999	NUMBER OF PATENTS 1994-1998†	CURRENT IMPACT INDEX 1999	CURRENT IMPACT INDEX 1994-1998†
U. CALIFORNIA	476/1	300/1	468	280	1.02	1.07
MIT	206/2	171/2	151	120	1.36	1.43
CALTECH	124/3	69/5	103	51	1.20	1.36
U. TEXAS	115/4	124/3	115	98	1.00	1.26
STANFORD	105/5	86/4	91	65	1.16	1.32
JOHNS HOPKINS	93/6	41/15	108	46	0.86	0.90
U. PENNSYLVANIA	92/7	62/8	64	51	1.44	1.21
U. WISCONSIN	84/8	69/5	87	62	0.96	1.12
U. WASHINGTON	82/9	45/11	53	32	1.55	1.42
WASHINGTON U.	70/10	29/20	60	27	1.17	1.10
COLUMBIA	69/11	47/10	59	34	1.17	1.36
CORNELL	64/12	64/7	69	52	0.93	1.24
U. NORTH CAROLINA	59/13	30/19	58	30	1.02	1.01
PENN. STATE U.	54/14	23/24	45	21	1.20	1.11
STATE U. OF NEW YORK	53/15	45/11	54	41	0.97	1.09
U. MICHIGAN	52/16	57/9	58	40	0.90	1.42
U. MINNESOTA	51/17	40/16	55	35	0.93	1.14
PRINCETON	48/18	22/26	30	16	1.60	1.34
CARNEGIE MELLON	45/19	21/30	26	13	1.73	1.60
DUKE	44/20	42/14	42	33	1.06	1.27
IOWA STATE U.	41/21	32/18	46	41	0.90	0.77
U. MASSACHUSETTS	41/21	15/40	59	16	0.69	0.94
U. ALABAMA	38/23	16/37	44	17	0.87	0.93
HARVARD	38/23	27/22	49	35	0.77	0.76
U. UTAH	38/23	28/21	37	31	1.02	0.91
U. ILLINOIS	36/26	13/43	34	17	1.05	0.75
U. PITTSBURGH	33/27	21/30	41	18	0.81	1.20
U. FLORIDA	31/28	43/13	55	46	0.57	0.94
MICHIGAN STATE U.	31/28	22/26	54	34	0.57	0.66
U. MARYLAND	31/28	22/26	40	23	0.77	0.97
RUTGERS	28/31	27/22	32	22	0.88	1.24
EMORY	28/31	23/24	28	17	1.00	1.37
BROWN	28/31	15/40	19	9	1.47	1.67
YALE	27/34	16/37	32	21	0.84	0.74
GEORGIA TECH	26/35	18/35	34	20	0.77	0.86
U. TENNESSEE	25/36	12/45	13	11	1.94	1.07
BAYLOR COLL. OF MED.	25/36	14/42	22	16	1.14	0.88
U. KENTUCKY	25/36	13/43	32	14	0.78	0.93
U. NEBRASKA	25/36	16/37	21	22	1.18	0.74
DARTMOUTH	24/40	5/49	10	5	2.44	1.08
N. CAROLINA STATE U.	24/40	37/17	25	30	0.95	1.25
PURDUE	23/42	20/33	23	17	0.99	1.14
CASE WESTERN RESERVE	23/42	10/47	29	10	0.78	1.02
TEXAS A&M	22/44	21/30	23	20	0.97	1.04
U. ARKANSAS	21/45	5/49	32	8	0.66	0.67
OHIO STATE U.	21/45	19/34	25	20	0.84	0.96
U. IOWA	21/45	10/47	34	18	0.62	0.59
U. CENTRAL FLORIDA	21/45	11/46	14	9	1.50	1.20
NEW YORK U.	21/45	22/26	28	21	0.74	1.04
THOMAS JEFFERSON	20/50	17/36	29	19	0.68	0.91

* includes all campuses in system; † annual average

all medical uses of Cox-2 inhibitors, or "super-aspirins," which last year beat Viagra's record as the fastest-selling new drug in history. When *TR* went to press, the school was suing Searle to block sales of the drug and was moving to negotiate licensing deals with that company and other manufacturers that could easily vault the Cox-2 inhibitors to the top of the heap.

Winners like these are manna for a technology transfer office, but they're not something a university can count on. So rather than betting on blockbusters, schools are increasingly seeking inventive ways to milk the most out of their bread-and-butter portfolios.

Take Pennsylvania State University, which currently ranks 44th in licensing income. "We are aggressively moving forward to hopefully change our success rate at capitalizing on our technology," says Gary Weber, director of technology transfer. Those efforts include building incubator space in the university's research park, courting venture capital as never before and signing what Weber terms "creative" equity deals.

In one striking example, Penn State bundled together three previously distinct pieces of agricultural intellectual property: a drug-delivery technology for controlling animal fertility, a chicken feed product Weber calls "poultry's Last Supper," which reduces *E. coli* contamination in slaughtered birds, and a genetic marker for "boar taint," an odor that can contaminate the pork from male swine.

Licensed separately, none of the inventions was likely to amount to much. But united, they formed the basis of an entire new company, whimsically christened EIEICO by the venture capitalist who funded the endeavor. Penn State took an equity position in the startup.

More and more, Weber and counterparts at other universities are looking for such entrepreneurial opportunities rather than one-shot deals. For one thing, ventures like these provide a vehicle to plow money back into the university to support ongoing development of the technology—and then to get new innovations out to market even faster. In the long run, such a continuous revenue stream—from a variety of small inventions—may outperform a blockbuster patent.

Whatever tack they take, university technology managers insist that, ultimately, it's not about an individual school's bottom line. The real point of the Bayh-Dole Act, they say, was to stimulate the U.S. economy and to get new technologies out into the marketplace—where they can begin to impact people's lives. Given the recent performance of the nation's top universities, it looks like Bob Dole has more than one thing to smile about. ◊

Tech Transfer Riches

INSTITUTION*	LICENSE INCOME (DOLLARS X 1000)/ RANK	RESEARCH EXPENDITURES (DOLLARS X 1000)	LICENSE INCOME AS % OF RESEARCH EXPENDITURES	LICENSES & OPTIONS YIELDING INCOME
U. CALIFORNIA (SYSTEM)	73,101/1	1,709,929	4.3	696
COLUMBIA	61,649/2	260,700	23.6	245
FLORIDA STATE U.	46,643/3	112,078	41.6	10
STANFORD	43,197/4	401,049	10.8	299
YALE	33,261/5	299,800	11.1	84
CARNEGIE MELLON	30,065/6	169,900	17.7	20
MICHIGAN STATE U.	24,337/7	193,611	12.6	41
U. WASHINGTON/WASH. RESEARCH FOUNDATION	21,299/8	432,383	4.9	204
U. FLORIDA	19,145/9	240,900	7.9	55
MIT	18,047/10	761,400	2.4	267
U. WISCONSIN-MADISON/ WISC. ALUMNI RESEARCH FOUNDATION	16,121/11	362,100	4.5	76
SUNY RESEARCH FOUNDATION	12,123/12	378,792	3.2	119
HARVARD	8,878/13	374,447	2.4	163
BAYLOR COLLEGE OF MEDICINE	7,247/14	207,100	3.5	102
U. PENNSYLVANIA	7,247/14	414,356	1.7	69
U. MICHIGAN	6,806/16	491,500	1.4	91
TULANE	6,588/17	87,858	7.5	23
JOHNS HOPKINS	5,513/18	987,464	0.6	149
CALTECH	5,500/19	151,000	3.6	50
EMORY	5,074/20	164,900	3.1	15
CORNELL RESEARCH FOUNDATION	4,798/21	343,007	1.4	163
RUTGERS	4,749/22	146,855	3.2	172
WASHINGTON U.	4,548/23	265,316	1.7	106
TEXAS A&M (SYSTEM)	4,414/24	393,720	1.1	137
CLEMSON	4,330/25	90,150	4.8	7

* individual campuses unless specified

Key

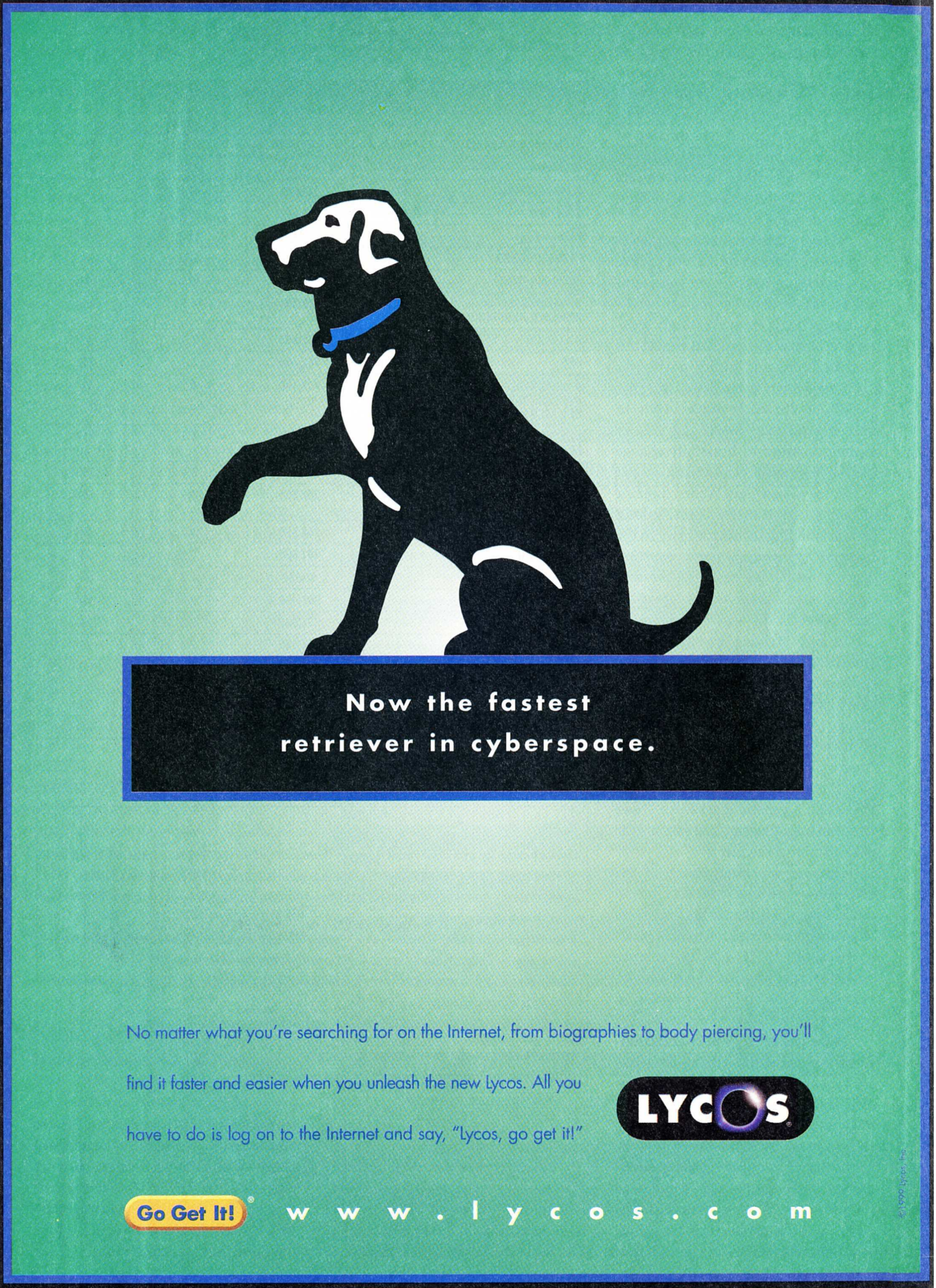
License Income: The gross license income received by the university in fiscal year 1998 minus license income paid to other institutions under agreement that year. Note: Rankings within this category reflect an institution's standing among all 132 U.S. universities surveyed by the Association of University Technology Managers, not just the 50 ranked highest in technological strength.

Research Expenditures: Total expenditures made in support of research activities, funded by all sources including federal and local government, industry, foundations, voluntary health organizations and other nonprofits.

License Income as Percentage of Research Expenditures: The adjusted gross license income, as described above, compared to total expenditure on research activities.

Licenses & Options Yielding Income: The number of licenses and options generating license income.

Data from the Association of University Technology Managers.
All figures in this table are from fiscal year 1998, the most recent available.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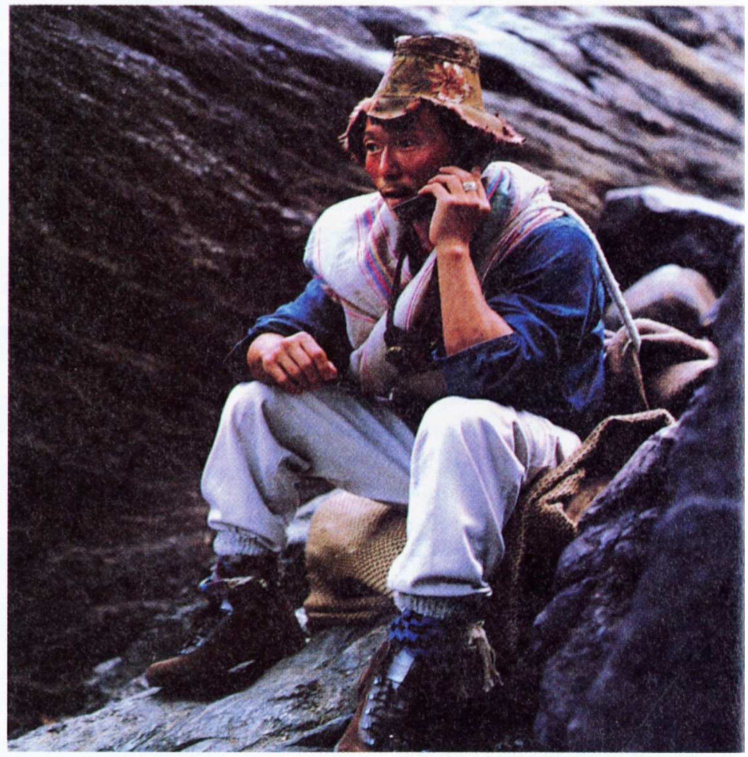
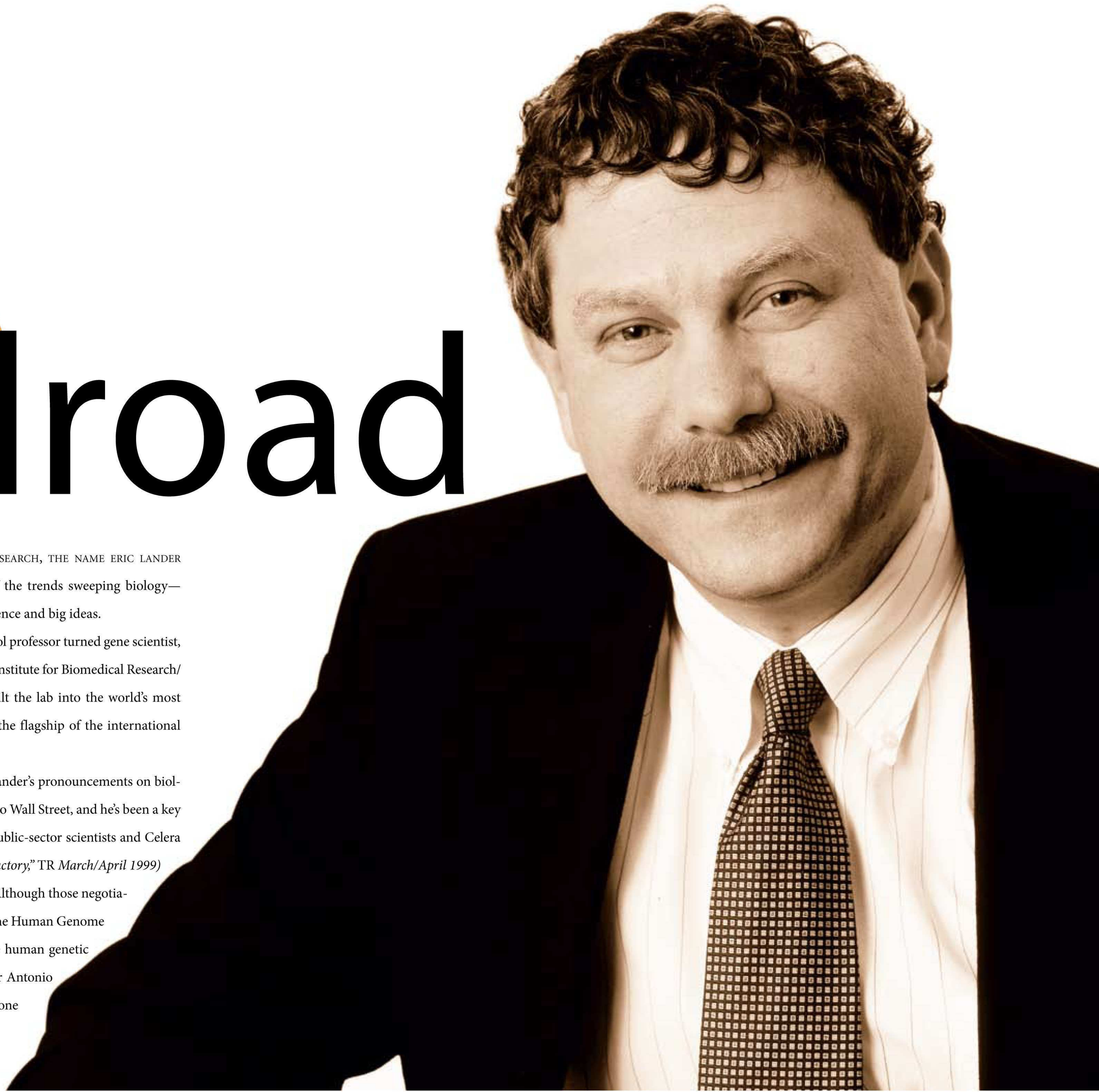


Riding the DNA Railroad

The Human Genome Project is as good as done, says MIT's Eric Lander. Now it's time to start thinking about how the data will be used.



Q & A

FOR INSIDERS IN GENOME RESEARCH, THE NAME ERIC LANDER evokes a palpable image of the trends sweeping biology—automation, computers, entrepreneurialism, big science and big ideas.

A mathematician turned Harvard Business School professor turned gene scientist, the 42-year-old Lander is director of the Whitehead Institute for Biomedical Research/MIT Center for Genome Research. Lander has built the lab into the world's most productive academic gene sequencing facility and the flagship of the international Human Genome Project.

Personifying the future of medicine isn't easy. Lander's pronouncements on biology's new age are in demand from the White House to Wall Street, and he's been a key figure in trying to broker a collaboration between public-sector scientists and Celera Genomics, the Rockville, Md., startup *("The Gene Factory,"* TR *March/April 1999)* that's racing to create a private copy of the genome. Although those negotiations collapsed amid angry accusations this spring, the Human Genome Project remains on course to produce a draft of the human genetic makeup within the year. *TR* Senior Associate Editor Antonio Regalado managed to catch up with Lander by phone early on a recent Sunday morning.

TR: What's been happening at your center during the last year?

LANDER: Well, it has been tremendously exciting. The international Human Genome Project had a three-year pilot project phase which was devoted to developing the methodology for how to sequence genomes. That phase came to an end in March of 1999, and we went from a pilot operation to a production level in excess of 15 billion nucleotides, or DNA letters, per year. We scaled up 20-fold over the course of about nine months, and we did so by less than doubling the staff involved in that process to about 80 people. And if we had had to go up 100-fold we could have done that too, because the whole thing is really quite automated.

TR: Last spring, the breakdown of negotiations between Celera Genomics and the Human Genome Project was front page news. What's behind that conflict?

LANDER: I think you put your finger on it. The origin of the conflict is that it has been on the front page of the newspapers from the beginning! What happened in May of 1998 [when Celera was founded] is that this all blew up in *The New York Times*, which decided to turn this into some kind of race and battle.

I think the public face of this, the journalistic feeding frenzy, has served no one terribly well and I am just not impressed by it. If you look at things from a 20-year perspective, this is about as exciting as the New Hampshire primaries. In the grand scheme of things people aren't going to care an awful lot who did what three months earlier than anybody else. As scientists we should look past all this, but that's hard with the media recognizing that this is a cheap and easy way for science writers to get their story on the front page. What can you do? People are very susceptible to that.

TR: Apparently, Celera and the Human Genome Project are still negotiating a joint publication of the genome data. What has your role been in these discussions?

LANDER: Oh, I talk to everybody in the community. This is a public service project and I think it would serve the world well for everyone to be talking. I find the racing and the acrimony to be kind of silly and I don't see why everyone isn't managing to work together in mature ways. What is the benefit of a field in which everybody talks to each other? Progress is made much more quickly. That has always been the case in science.

> "The international Human Genome Project is about guaranteeing that the sequence of the human genome will not be a trade secret."

TR: What does it mean for the genome project to be finished?

LANDER: The truth is that the human genome is going to have all kinds of nasty little bits that are hard to fill in at the end: the middles of chromosomes, called the centromeres, the ends of chromosomes, called the telomeres, and so on. This is not like the transcontinental railroad, where at some point someone is going to nail in the golden spike, and then and only then can you go cross-country. There is no golden nucleotide to be nailed into the double helix at the end.

What's important is that every bit of the DNA railroad is already being used today. As of this month, more than 85 percent of the human genome is freely available on the Web. So the notion that biology will be suddenly transformed when we cross a specific finish line is wrong. The point is that biology has already been transformed. The race is over in the sense that everyone is taking the human genome for granted. That is the achievement right now.

TR: What are the next big opportunities in genomics?

LANDER: Well, let's start with the basic research question, which is how do you use the information in a genome to figure out how physiology really works. The genome is a very elaborate program, and we don't know how to read it. It's as if we have some ancient computer code that was written three billion years ago and now we are trying to figure out what it does. I think what biologists are going to be doing for the next decade is figuring out the circuitry of the genome by monitoring how the 50,000 to 100,000 genes are turned on and off and how all the proteins come on and off in the cell.

A lot of technology is going to be needed to do that, so I also think that detector technology [such as gene chips] is going to be a driving force of genomics in the future. I see a real merger of physics, chemistry, biology and computer science to be able to build these detectors and interpret their results.

TR: How will that affect the creation of new drugs?

LANDER: It was noted about 10 years ago that in order to maintain the valuation of the pharmaceutical industry it would be necessary for the typical pharmaceutical firm to bring to market three new drugs each year. In fact, most companies bring to market one new drug a year, at most. So there is a huge productivity gap. And the reason for that is that making a new drug is not an act of engineering. It's an act of art mixed with a lot of luck.

When you make a new drug you often have no idea whether the target you have chosen is valid, and no way to know whether your drug will be non-toxic or if it will be absorbed and metabolized by a human in the right way. Right now the only way to find out those answers is to pay hundreds of millions of dollars to test the drug in human clinical trials.

Imagine what would happen if one could reverse that by using technologies that had high predictive capability and could be deployed early in the process. That would mean when you go to do your clinical trial, there would be a very high probability of success, compared to the current low probability. Well, that would have a huge impact on the number of drugs that one can develop. That is what the industry sees as the promise of genomics and of biotechnology. When people look back 30 years from now, they are going to be looking back from a pharmaceutical industry that is an engineering industry. And they are going to marvel that anything at all got done in the 20th century.

PREVIOUS PAGE: SAM OGDEN


YEP, YOU'RE IN E-COUNTRY NOW.
A SMALL NEIGHBORHOOD GET-TOGETHER. NEXT THING YOU KNOW, THE FUTURE OF INFORMATION TECHNOLOGY IS CHANGED FOREVER. THAT'S WHAT HAPPENS WHEN LIKE-MINDED THINKERS AND FELLOW VISIONARIES SHARE THE SAME CARPOOLS AND ATTEND THE SAME LITTLE LEAGUE GAMES. NO WONDER PEOPLE ARE PASSIONATE ABOUT LIVING HERE. VISIT WWW.E-COUNTRY.ORG TO LEARN MORE, OR CALL 703-790-0600.
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TR: Your center works closely with industrial partners, including Bristol-Myers Squibb, Affymetrix and a company you helped start, Millennium Pharmaceuticals, to develop just such predictive technologies. Have the lines between academia and industry been redrawn?
LANDER: Oh absolutely, but industry and academia still have very different jobs. Academia continues to be the place to make the basic discoveries that are not "appropriable" as private intellectual property. So for example, the understanding of cancer and how a cancer cell works are things that no company can lock up and therefore it makes no sense for companies to be investing in. It's what is called a "public good."

I think the majority of biology remains a public good, in the sense that it is fundamental knowledge. The minute something becomes appropriable in an economic sense, however, it often makes more sense for industry to take it over. What used to happen is that the gap between the fundamental and applied knowledge was decades in biology. Now the gap is six to 12 months. So it means there is a much tighter coupling and a much greater intellectual interchange between the two.

TR: Your industry partners have commercial rights to improved genomics technologies developed with their money. What kind of restrictions does that put on you as an academic?
LANDER: The conditions of that alliance are very explicit in that regard. We are free to publish or speak about anything as long as we have given 60 days' notice. The 60 days are there to be able to file any patents that should be filed. We have yet to find this to be a serious limitation, because it's hard to get anything in a scientific journal faster than 60 days. Also, the benefit of this industrial consortium is not so much specific patents as it is a community of researchers both in academia and industry who are working together to push the edge of the technology.

TR: Is the Human Genome Project racing in order to prevent Celera from patenting human genes?
LANDER: Really, the issue has less to do with patents than with secrecy. The international Human Genome Project is about guaranteeing that the sequence of the human genome will not be a trade secret and will be freely available in everyone's hands, with no restrictions on its distribution or on its analysis. That is our purpose and that is the race that we have won.

The patenting problem is a decade old, and Celera is a Johnny-come-lately. Most of the patents that are going to matter are held by the five or six genomics companies that preceded Celera, like Human Genome Sciences and Incyte Genomics. While I do agree that there have been very serious problems with patent law, Celera is not going to be the principal beneficiary of any of that.

"All patents are a bargain between society and inventors made to incent innovation. The question is, what sort of bargains do we want to strike?"

TR: What is your view of gene-related patents?
LANDER: All patents are a bargain between society and inventors made to incent innovation. The question is, what sort of bargains do we want to strike? For the last three years the Patent Office was saying that naked gene sequence about which you know nothing, or very little, is patentable. When something is trivial and involves no substantial inventive step, like running a gene sequencer, it's my sense that society shouldn't be setting the bar so low.

In fact, the difficult step is figuring out what a gene does and what it's good for. And therefore we ought to have a social policy that sets the bar there. Recently, the Patent Office has begun to move in the right direction, although it still has a ways to go. We don't want to find that we have given away the monopolies to the people who did the easy steps and have left less to incent the people who have to do the hard steps. Pharmaceutical companies already are worrying about working on a particular gene for fear that some other company has a patent on it. Well, the big losers in this case are patients.

TR: The Hollywood movie *GATTACA* is about unhappy people living in a world where success and social status are determined by their genes. Is that where we are headed?
LANDER: That's the idea of genetic determinism, and I am quite opposed to it. Privacy and nondiscrimination are really the two big issues and there are many people, including myself, who are worried that our society has not put in place the proper protections.

I believe in absolute privacy for genetic information. I want this to be information that every patient can have access to on his or her own terms. And I don't want any insurance company, any employer or any government to have any say over that information or to be able to gain access to it without the explicit consent of the patient.

I would also like to see strong statements in legislation that say that genes are not an allowable basis for discrimination. There are a lot of things that we have decided that it is just flat-out wrong to discriminate on, such as race. Well, I don't see why we shouldn't put genes in with that. And if there are any exceptions to be drawn, we can worry about that later.

TR: In the absence of any national legislation, are there a lot of examples of genomic information being misused?
LANDER: Examples of misuses still remain few because, as with many technologies, there is a phase where it is not efficient to use this information and so people don't gather it. But then there comes a tipping point after which it is very efficient, but by then it's too late if you don't have the legislation in place. It's a mistake to conclude that we have a long time to sort this out, because a decade from now it will probably be too late. We have to get everyone to understand that the human genome should never be used as a tool to divide people. ◊

Pharma's Blockbuster Habit

About 15 years ago, I traveled to Nutley, N.J., to interview a molecular biologist at Hoffmann-La Roche. I vividly recall my host waving at an impressive little skyline of buildings worthy of a college quadrangle and proudly saying, "Valium built all this." As recently as a month ago, when I visited the gleaming research and development complex of SmithKline Beecham just outside Philadelphia, my scientific host waved at an expanse of tinted-glass buildings and explained, "Tagamet paid for all of this."

I'm sure they say the same thing in Indianapolis about Prozac, and in various townships of New Jersey about Claritin and Lipitor, each of which racked up annual worldwide sales in excess of $2 billion in recent years. For many years, Big Pharma has had a bottom-line love affair with Big Drugs—blockbusters that generate billions of dollars in sales each year.

Part of the reason is history. Discovering and developing drugs has always cost a bundle, although one could argue that hyperbole as well as inflation has contributed to the steadily rising estimates for the cost of developing a new drug. Little more than a decade ago, the standard figure was $50 million to $75 million to bring a new drug to market, but the pharmaceutical industry now likes to float a figure of $500 million. (It's a rickety number that conveniently includes the costs of drugs that died on the way to the market, including ones that should have been abandoned but weren't.) But let's stipulate: There's no question drug development is a dicey business, where bad luck, unanticipated side effects and unexpected lack of efficacy can blow holes in any company's pipeline.

Genomics tells us that one size (of drug) does not fit all, contradicting the "blockbuster drug" philosophy. How will the pharmaceutical industry react to this new reality?

Perhaps a more compelling reason is the view ahead: After a quarter-century of molecular biology and the first early returns from genomics, the industry is confronted with what Big Pharma R&D chiefs routinely describe as a "cornucopia" of possible gene-based drug targets. It's going to cost big money to place a lot of chips on the genomics game board. Moreover, a lot of these genes do not come with operating instructions and an owner's manual, so companies will have to do the kind of basic biology traditionally pursued by academia. With future R&D budgets projected to be between $4 billion and $5 billion, companies need enormous revenue streams to feed the development beast.

But what if the blockbuster strategy represents yesterday's wisdom? If the philosophy behind genomics is correct, companies may face what might be called "the allele gap"—or, to invoke a popular phrase from my college years, a kind of "polymorphic perversity." As each new gene is identified and characterized, drug developers have a potential target for therapy.

Yet the ultimate message of genomics is that one size (of drug) does not fit all, which contradicts the basic philosophy that drives blockbusterdom. The fact is that each gene has polymorphisms—variations (or alleles) on the standard-issue gene. Many of those variations are expected to correlate with disease states, but even so, not all the variations are likely to respond to the same drug. The irony of genomics is that the more precise the science, the smaller the potential market may be.

You don't have to be a Bolshevik to understand that "customized medicine" are fighting words in the traditional economy of drugs. They take the mass out of mass market, and remove scale from economies of scale. I have seen biotech executives recoil at the prospect of developing a drug that would benefit "too few" people.

In the long run, a company that develops a broad portfolio of "modest" drugs—as in annual revenues of $300 million to $500 million—may do just as well as a company that continually searches for a blockbuster. Lip service is already being paid to the argument that customized, genomics-based drugs will be more effective and come with fewer side effects, and therefore will be able to attract a significantly higher price.

That may be. But here is a modest cautionary note: For 10 years, scientists have been selling the genome project to the public on the basis of the way it will revolutionize medicine. If, because of the blockbuster mentality, a lot of genomically based drugs do *not* get developed simply because the market looks too small, or if these new drugs are even more stratospherically priced for consumers, you may hear a public outcry that will make the current debate over the cost of prescription drugs sound like the balcony scene between Romeo and Juliet.

It will be fascinating to see how the pharmaceutical industry handles the glut of possibility in the era of the genome. After you've seen a single drug literally transform the landscape of your R&D campus, it's easy to understand the allure of the blockbuster syndrome. To mix drug metaphors here, it may be hard for Big Pharma to kick the habit. ◊

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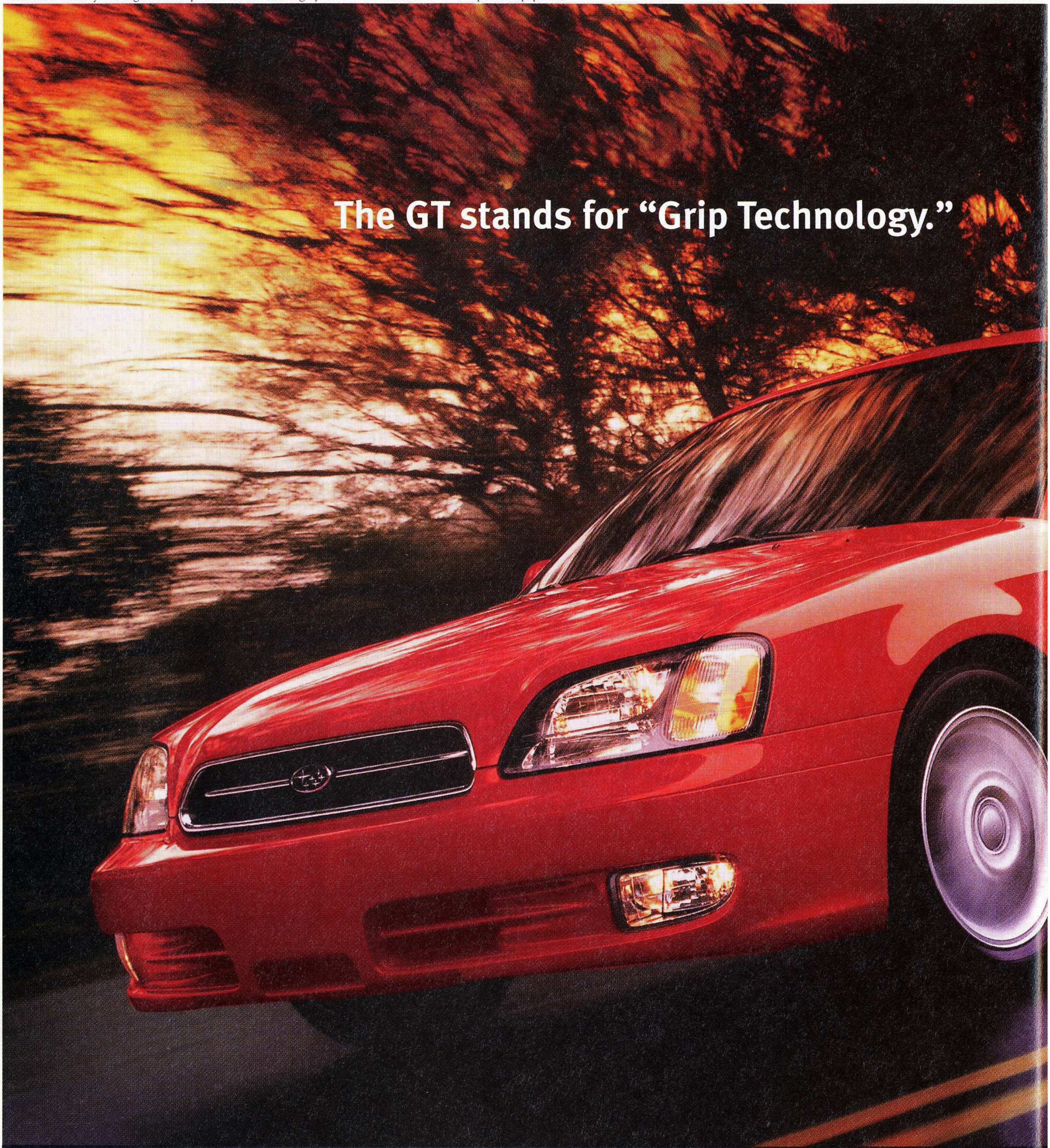

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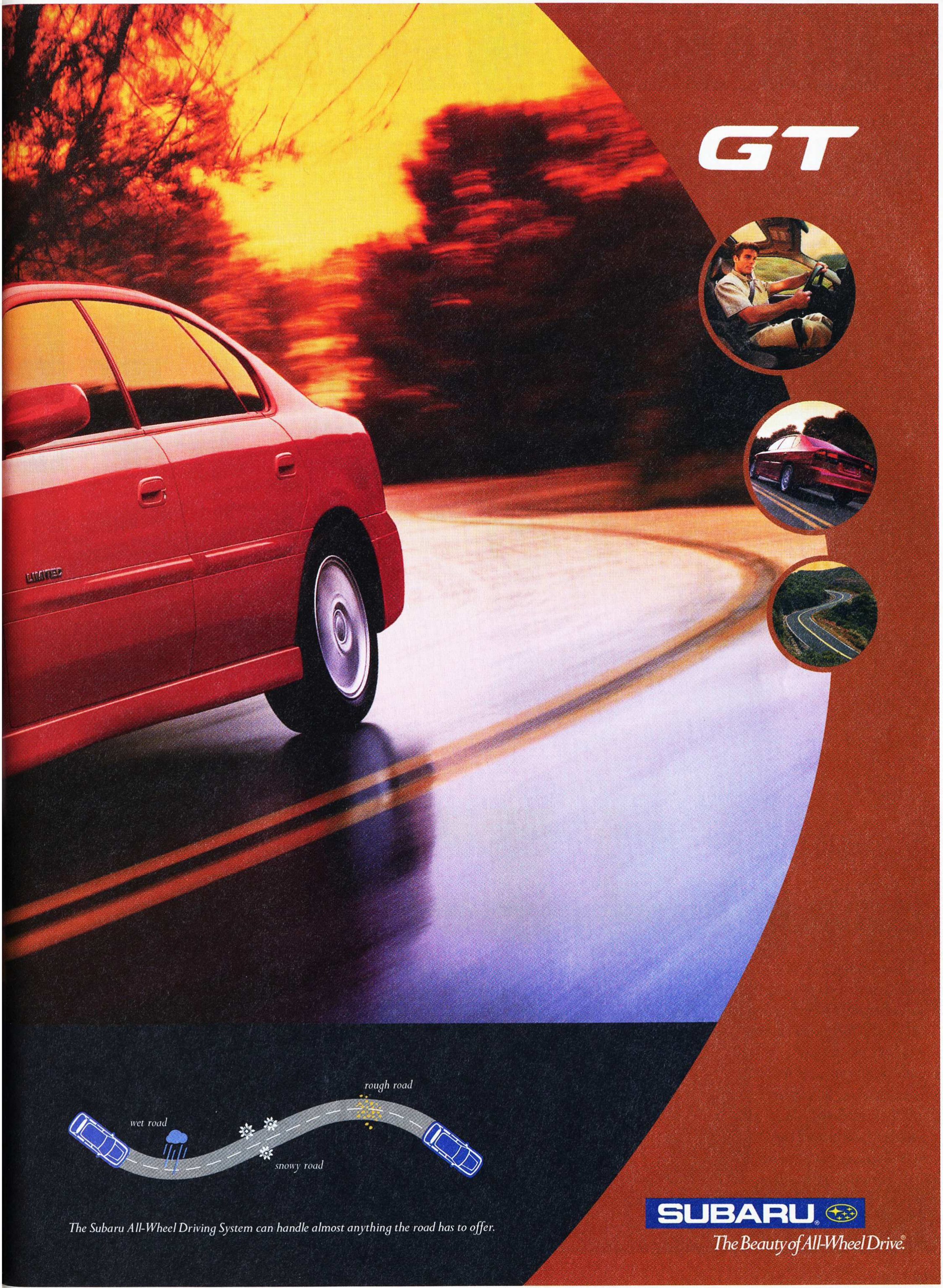
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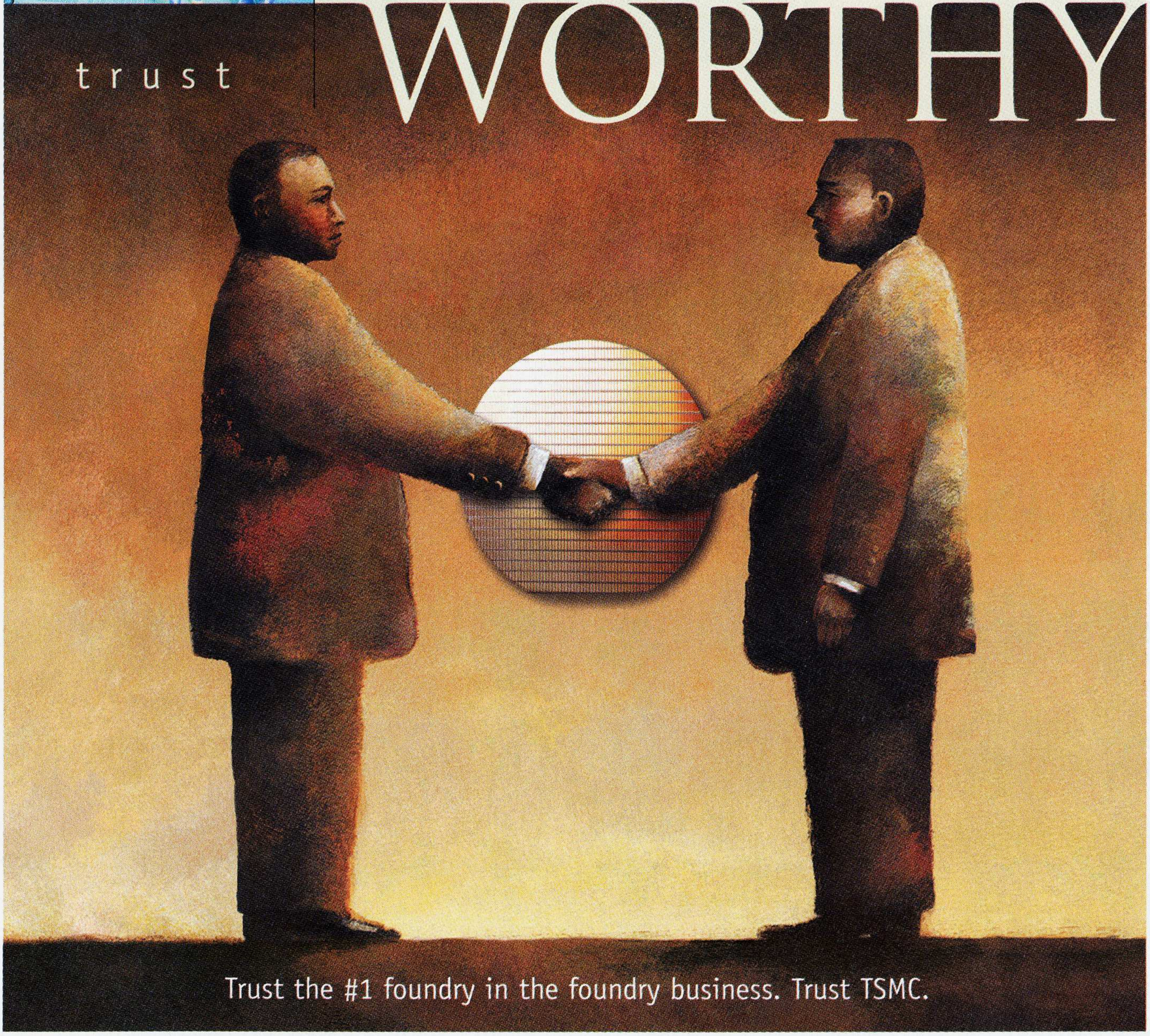
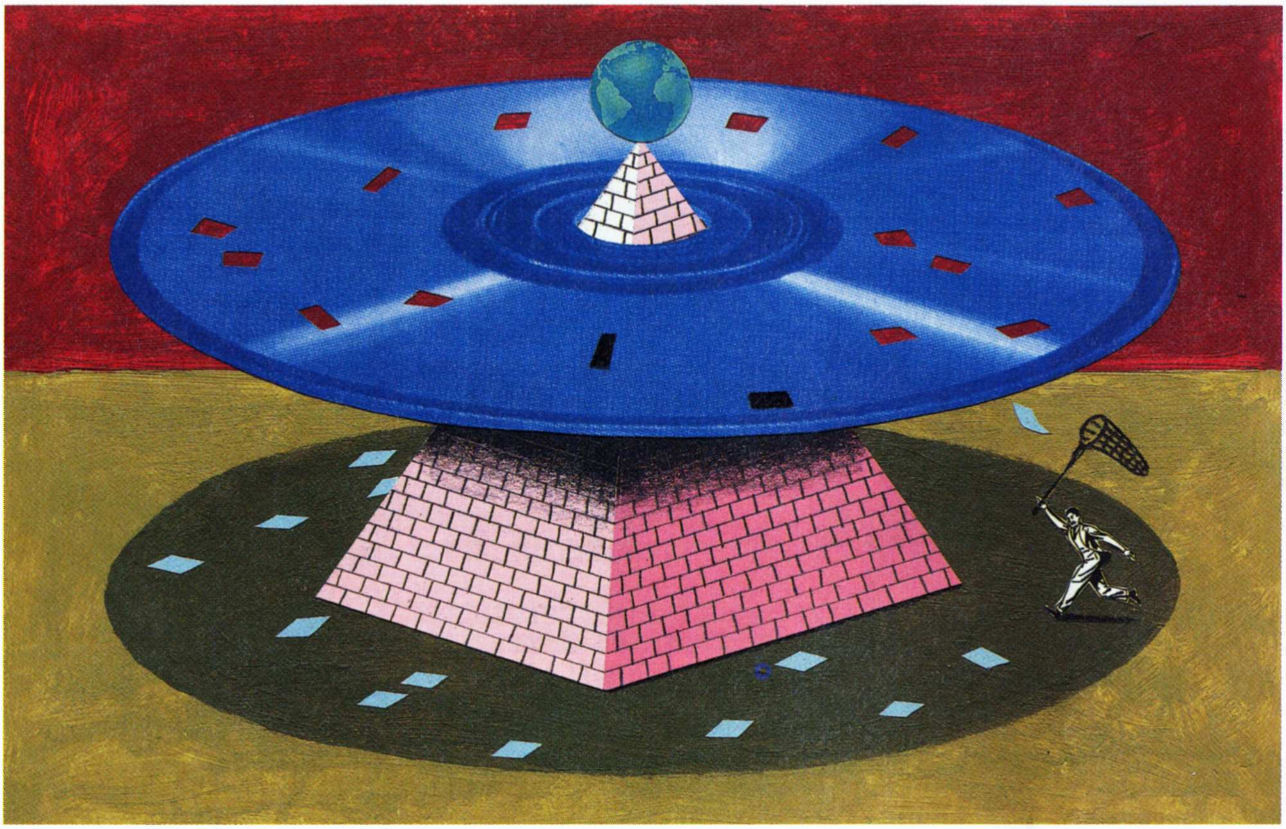




GENE GREIF

VIEWPOINT | BY NICK MONTFORT

In Search of Webs Past

"Survival of the hittest" leaves a precious record crumbling

THINK OF THE WEB AS AN ENORMOUS, slow hard disk. Shared by the entire world, this disk holds a record of radical media experimentation, the history of a form that sprang up less than a decade ago to infect popular consciousness and transform the way we use information. Yet despite a few archival projects, no one is backing up our collective disk.

That's not what you'd conclude from a casual glance at leading Web sites. Almost every major Web magazine has an "archive" which holds old content. These are not real archives, however, any more than home pages are real homes, or real pages. They do not preserve early versions of the site—they only keep the most popular old content online and accessible, for the sake of additional banner-ad revenue. The archive of *HotWired* is typical in leaving out some early content: A serialized novel and an advice column, early Web-based experiments in these forms, are omitted. The old content that remains online is seldom in its original format, even though form is of clear importance to the Web's development.

Those who forget the past are condemned to reload it. The Web's advance has been rapid, but that's all the more reason to study it with care. In all the confusion, it's easy to lose track of what publications and business models have already been tried, and with what results. For students of new media, understanding the sometimes arcane structure of Web sites is even more difficult without knowing about what has come before. Even important political phenomena such as the groundswell of opposition to the Communications Decency Act cannot be accurately considered without looking at the essential, primary source: the blackened Web pages of 1996. From a business, media-studies and historical perspective, the Web's past is worth remembering.

The Web began as an all-text system at the end of 1990, used by an international community of physicists. In early

1993, it had fewer than 100 servers providing scientific and technological information. The turning point came in November 1993, with the release of the Mosaic browser, well-designed software that could load and display graphics. Mosaic, which came from the National Center for Supercomputing Applications (NCSA), was not the first graphical browser. It was, however, simple, effective and compatible with different operating systems. Mosaic led to incredible innovation in the following years. By the end of 1994 the Web's 2500 servers hosted cultural magazines, banner advertising and unique efforts such as the Internet Movie Database. That project, a collaborative attempt to create a comprehensive filmography of the world's movies, would have been impossible without a far-reaching data repository like the Web.

Scrambling to put together Web sites with no guidelines or precedents, early Web developers tossed together a salad of old-media forms and genres, graphic and interactive design and both esoteric and offhand document organization schemes. In this experimental time, all of today's principles of cross-platform design and site navigation were devised. "Survival of the hittest" determined what types of sites worked. Universities found the Web an easy and money-saving way to provide information to different groups: prospective students, enrolled students, alumni and others. Hardware vendors such as Dell and Cisco found that Web sites perfectly suited their technically proficient buyers. Even the Web's losers made interesting advances in interactive design, online writing and business development, some of which were simply before their time. Security First Network Bank launched in 1995 as the first Internet bank, for instance. The vice president of Chase Manhattan's e-commerce division denounced it as "a dismal failure" in 1998, when it was sold, along with an associated software company, to the Royal Bank of Canada for $29 million. Yet major players like American Express are now starting to offer similar Internet-only banking services.

The innovation that characterized the mid-1990s is a thing of the past. It has been replaced by many different forms of creative development, of course, as designers refine the fundamental advances made during the Web's early era. But by the end of 1996 the Web's basic conventions had been established, in only three post-Mosaic years. For the printed book, this early developmental period—in which "incunabula" were printed (and things like page numbers and tables of contents were figured out)—lasted about fifty years.

What has happened to the actual Web pages that were marked up during the Web's salad days? Some are still around, but for the most part they are changed beyond recognition, and the original versions exist only on some obscure and offline hard disk. The online novels *Delirium* and *As Francesca* and the early Web serial *The East Village* can no longer be seen—and those works were offered on major Web sites whose parent companies are still around. Some concerted attempts are being made to preserve material from this era: The 1996 presidential election Web sites, for instance, are the target of a current Internet Archive project. (That organization also plans to maintain copies of the whole Web, stored at various points in time.) The election sites have popular appeal as candidates for preservation. They're considered notable by the offline world and are of some importance to this country's political history. But they're not relevant to the development of the Web as a medium.

Those who forget the past are condemned to reload it. If we only save a handful of Web sites, how will we remember our digital history?

Consider instead the first daily Web magazine, the cranky and crack-joke-filled *Suck*—an exemplary first-wave site (to which I contributed some pseudonymous items). *Suck*, which appeared in August 1995, put fresh daily content right on the home page instead of burying it within the site. Each elegantly laid-out column of text tore into many of the day's sillier Web experiments: Turner Entertainment's *Spiv*, Web soap operas like *The Spot*, the subscriber-based model of Microsoft's *Slate*. In the early days, this edgy text was illustrated with images lifted from the sites it panned, presented at a characteristic tilt. *Suck*'s writers figured out how to use the hypertext medium cleverly. They linked to pages not to refer the reader to further information, but to lampoon absurdities and recontextualize Web pages humorously. For instance, a link to the *Netly News* (a publication of Time Warner, presented as part of the Pathfinder site) wasn't there so the reader could actually learn more about some newsworthy topic. It was to point out how the tone and daily release of the *Netly News* was weakly ripping off the *Suck* concept.

Suck is still up and twitching. It has gone through expansion and reduction, and been sold twice—first to Wired Digital and then, along with other Wired Digital properties, to Lycos. The original simple and direct design has been made more convoluted by upgrades, but catchy illustrations have been added. The writers now take on a broader range of pop-culture targets, humiliating TV programs and youth subcultures, not just Web sites. The site has stayed irreverent and somewhat relevant, and has not become as thoroughly encrusted with features and rimmed with "portal" links as has most of the Web today. But looking through an early *Suck* article now reveals the fate of many mid-decade Web pages. The writers, complaining about how stupid and doomed to failure many of the early attempts really were, were largely right. Many witty links are now dead, leaving the wry hypertext without its digital straight man.

The decay of 5-year-old digital humor may not be cause for mourning, except among scholars of new media. The loss of early Web sites isn't entirely academic, though. Those who are plunging into startups today should look closely at what succeeded and failed back around 1995, when ".com" was a dirty phrase instead of a lucrative suffix. Take, for example, one of the Web's most successful companies, Yahoo!, which started as a student home page at Stanford Uni-

versity. Yahoo! gained popularity and, with its more useful organizational scheme, eclipsed the well-established index of the day, NCSA's What's New. Of course, many of the sites this early Yahoo! actually linked to are gone. The real woe is that businesspeople hoping to emulate Yahoo!'s success, as well as students of computing and media history, can't easily see what version 1.0 of Yahoo! looked like and compare it to the rival index. The original Stanford home page—the Web's first table of contents—is long gone. The Internet Movie Database has been even more drastically transformed. The collection of movie reviews, originally contributed by volunteers who had no financial interest in the films they wrote about, is now owned by Amazon.com and used to market videos.

The disappearance of valuable Web content will not be stopped by simply selecting "Save As...." Despite the digital nature of online information, real archiving comes at a cost. For one thing, sites that are stored for posterity must be maintained in a way that is verifiably legal and respects the copyright and privacy interests of content creators. Legacy browsers have to be kept on hand, too, so one can see the early Web in the way surfers encountered it back around 1994. Finally, magnetic media and even CD-ROMs degrade after decades, and data has to be copied over every few years if the material is to be safely preserved.

The Internet Archive project is taking such factors seriously, although that project has made some curious omissions. For instance, although one of the project's directors is a librarian, the Archive does not have an archivist on its board. The organization's recent approach of focusing on a handful of specific sites is sound, but pages of greater importance to the culture and medium of the Web could have been selected. Choosing a few sites, though, is certainly a better idea than the Internet Archive's original plan to preserve every bit of the Web using data from the company Alexa—a Sisyphean task to which the organization remains devoted. The issues of copyright, privacy and access are tractable when specific sites are chosen for preservation. To write the whole Web to a giant array of hard disks, on the other hand, is a showy and largely useless technological gesture.

The Web sites of lasting interest are early versions of innovative business, publishing and artistic ventures—not Ross Perot's home page. Unless we act to preserve important sites, many of which are already offline, the Web's origins will become even murkier. Developing the Web intelligently, and trying to understand it, will be made harder by our lack of perspective.

It's quite possible that the origins of the most technologically advanced worldwide system for publishing and communication, now less than a decade old, may one day be known only through isolated scraps of information and the hazy recollections of aging geeks, trying to recall when they created their first animated GIF, or when they first used a Web conferencing system, or when they visited Yahoo! back in the day, when it was on konishiki.stanford.edu...or was that akebono.stanford.edu?

Join Montfort and TR *readers to discuss this essay at www.techreview.com/forums.*

MIXED MEDIA

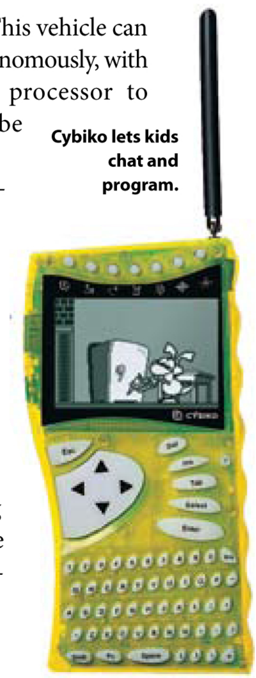
Some Creativity Required

Are toy makers finally getting the message?

IT HAS BEEN 30 YEARS SINCE MIT'S Seymour Papert first asked: "Should the computer program the kid or should the kid program the computer?" Until recently, the toy industry has taken the former approach, churning out high-tech toys that do little to enlist children's native creativity. Technology, says Henry Jenkins, director of MIT's Comparative Media Studies program, has mostly been used to create dolls that simply "say something other than 'Mommy.'" A welcome change seems to be in the works, though. Starting last year with the Lego Mindstorms construction kits, toy makers are—tentatively—introducing products that offer kids the opportunity to program, create and invent.

Mindstorms, which enables kids to build and program mobile robots, was the first extensively programmable item to reach toy-store shelves. Kids drag and drop code components to define a programming unit called a procedure, which is sent via infrared to a processor mounted on a Lego vehicle. This vehicle can then move around autonomously, with sensors alerting the processor to obstacles that must be navigated around.

This spring, Mindstorms got company as a few new gadgets followed its lead. One is the Cybiko, a kid-friendly personal digital assistant; the other is a crude, inexpensive video camera that could put digital moviemaking into the hands of the young and allowance-dependent. Both offerings conform to the view articulated by Media Lab professor Justine Cassell, who with Jenkins edited the 1998 book *From Barbie to Mortal Kombat*. The industry's emphasis on "smart toys" is misplaced, argues Cassell: "It shouldn't be the case that the toy is smart; it should be that the toy allows the kid to be smart, or creative, in new ways."



Cybiko lets kids chat and program.

CYBIKO

Opportunities for creativity aren't always as obvious as with the Papert-inspired Lego Mindstorms. Sometimes even a slick-looking consumer gadget packs unusual opportunities. The Cybiko—with its wireless communication and tiny keyboard—might be the offspring of a Nintendo GameBoy and an Apple iMac. Created by Chicago-based startup Cybiko Inc., the handheld game system offers several unusual, enabling features.

The wireless communications system allows Internet-style chat with nearby Cybiko users, making it a sort of digital walkie-talkie and providing a new channel over which many kids can communicate at once. A novel

DIGITAL MUSIC

Copyright on the Fly

Music lovers have reveled in—and devoured—free digital music. The catch is that artists' property rights got lost in the shuffle as online consumers ignored copyright laws that are meant to prevent the unauthorized copying and distribution of recorded music. Without a secure way to track music files online, artists find themselves losing control over their own creations as well as the ability to profit from them.

Enter Digital Media on Demand (DMOD), a Boston-based startup that has made secure distribution of online music its mission. DMOD's four cofounders recognized before most others that digital distribution necessitated technologies to protect and manage artists' rights; they have spent the past several years developing an encryption protocol that will allow artists to encode and track online files. Whereas most encryption systems use one key to provide secure, limited access to a file, DMOD's uses many. In fact, according to Sam Headrick, director of development, a different encryption key could be applied to each second of audio, or for each line of text. "This increases the complexity of cracking the file by many degrees," Headrick says.

DMOD's artist-rights protection squad.

DMOD

DMOD's protocol provides additional security through "watermarks." Each watermark stamps content with new data—inaudible to the human ear in audio files—that traces the file back to the artist who uploaded it and to the consumer who downloaded it. The protocol encrypts files "on the fly," as they're delivered. "At the moment you decide to acquire a piece of content, the keys are generated and the file is encrypted based on those dynamic keys," Headrick explains. "Every transaction is a separate and autonomously secure data transmission."

Security precautions like these could put copyright control back in the hands of artists. "Even if content owners want to give files away for free, they should still be able to track their files," says DMOD chief operating officer Brett Fasullo. "Secure distribution means a lot more than being able to sell media files online."

—**Rebecca Dorr**

feature is the Cybiko's creativity-fostering software. A text editor is standard; connecting the Cybiko to a PC lets kids load it with new graphics and music-creating software. Cybiko will soon make its CyOS operating system and development software available for free, allowing kids to program it. As *TR* went to press, Cybiko president Donald Wisniewski said two toolkits would be available for the handheld this spring. One is a "drag-and-drop" editor to change the difficulty of existing games; the editor will be accessible to young children. The other is a full software development kit, created for professional developers, that will likely get some use from teenage programmers.

Another new toy might allow high-tech media-making, turning the tables on Disney and Nickelodeon by allowing kids to become filmmakers. No release date has been set for IntelPlay's Digital Movie Creator, a prototype of which was demonstrated at the International Toy Fair in New York in February by the Intel-Mattel joint venture. The camera is reminiscent of Fisher-Price's Pixelvision camera of the 1980s, which flopped in the toy stores but which has since become popular among some independent filmmakers because of its uniquely blocky black-and-white images. The IntelPlay system would provide an additional benefit over the Pixelvision, allowing kids to edit their films on the computer to create a sophisticated narrative film or a whimsical video collage.

Other promising products provide new interfaces to the computer, and are already on the market. IntelPlay's QX3 computer microscope makes possible high-tech scientific exploration, and a way to tap the computer's image-enhancing properties to help explore the microworld. Zowie Intertainment, founded by TR100 member Amy Francetic, sells toy kits that function as interfaces to an onscreen story world. In one kit, a pirate ship and the people on board can be used to control action on the computer screen, encouraging children to act out different stories.

Most of the toy industry remains more interested in branding and TV tie-ins than in Papert's provocative question. But one can hope that these few promising technological toys are the beginning of a new trend, not just a momentary glimmer.

— **Nick Montfort**

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DUKE2000.COM

Duke sizes up the opposition...

One entrant in this year's presidential race is spanning his own digital divide, using the latest in real-time computer animation to emerge as the first virtual candidate. Uncle Duke, the *Doonesbury* comic strip character seen in 1,400 newspapers worldwide, has grown from a flat, cigarette-holder puffing cartoon into the three-dimensional, political trash-talking star of his own Web site (www.duke2000.com), complete with virtual smoke. The animation was created by Dotcomix, a San Francisco-based Internet studio. For virtual Duke, an actor wears a body suit with motion-capture detectors while a puppeteer manipulates facial expressions. Says executive producer Buzz Hayes: "We could apply the same technology to Bush and Gore—to make *them* more animated, too."

In an exclusive interview with *TR* contributing writer Steve Ditlea, candidate Duke unveiled his views on high tech—via campaign manager Garry Trudeau.

...takes the pulse of Hollywood...

TR: Are you taking positions regarding technology?
DUKE: No, my campaign is *faking* positions regarding technology, just like the other campaigns. The difference is we're upfront about it. I mean, who's got time to keep up? Just ask Bill "an Internet browser is a trivial piece of software" Gates.

TR: What do you think about the digital revolution?
DUKE: I'm for it. I can lay out my agenda, spam voters and sell junk from my Web site—all without leaving my campaign headquarters at the Coon Rapids E-Z-Rest Motor Court. And I'll be selling all my ambassadorships on eBay.

TR: How significant is the "new economy"?
DUKE: Well, so far, my campaign is only being sponsored by old-economy companies—Absolut, Keebler Cookies and most recently Brown & Williamson, which has signed on as the Official Nicotine Delivery System of the Duke2000 Campaign. We'd be open to new-economy sponsorships, provided they pay in cash—I won't be held hostage to some socially impaired teenager's ability to close mezzanine financing in a bear market.

TR: Should Internet transactions be taxed?
DUKE: Who talks about new taxes during a campaign? Serious candidates only talk about tax cuts—free money. And I've already said I'll double whatever anybody else offers. I'm not a fringe player on this issue.

...and confers with an adviser.

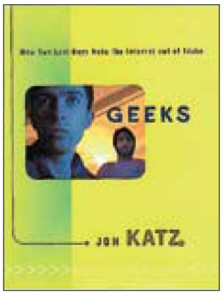
TR: How do you feel about censorship of the Net?
DUKE: Look, we should have learned long ago that one person's porn is another person's social life. Now, obviously there are strong individual cases to be made for censorship—MarthaStewart.com, iVillage and such—but no one's forcing you to log on. And as for all those bomb-building Web sites, do you really want to live in a country that restricts the rights of the legitimate, law-abiding sport bomber? I'm just not comfortable with that.

TR: Are you in favor of human cloning?
DUKE: The potential for abuse is enormous. History would never forgive us if we were to produce another Linda Tripp.

PAGES | BY WADE ROUSH

Digital Redemption

GEEKS: HOW TWO LOST BOYS RODE THE INTERNET OUT OF IDAHO
By Jon Katz
Villard, 209 pp., $22.95



DURING THE WEEKS OF media-stoked paranoia after the Columbine High School massacre, writer Jon Katz became a conduit for thousands of outcast teens who were suddenly singled out as potential sociopaths simply because of their fondness for the Internet, dark clothing or fantasy video games. Katz's columns at www.Slashdot.org didn't defend the killings, but they did explore the special hell endured by high-school geeks at the hands of taunting peers and suspicious adults, and they generated megabytes of e-mail from alienated kids and concerned teachers and parents.

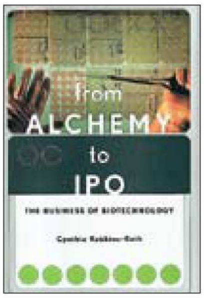
The timing of the massacre and the outpouring around Katz's columns were oddly appropriate, since Katz had just published a *Rolling Stone* article about Jesse Dailey and Eric Twilegar, two "Pissed-off, Castoff Nineteen-Year-Olds" who "Escaped a Seven-Dollar-an-Hour Future in Dead-End Idaho and Rode the Internet out of Town." The heartbreak of Columbine made Jesse and Eric's escape seem all the more providential, and created a compelling moral subtext for Katz's book *Geeks,* a greatly expanded version of the magazine article.

Geeks is technology journalism with a highly personal twist, making it one of the rare books I've read for this column that stayed in my thoughts for weeks. Katz, who is in his 50s, reveals himself as a former "lost boy," unable to cope with authority and destined early on to fail in a string of schools and jobs. He sees some of himself in Jesse and Eric, with one big difference: These boys were born into the Internet age. Despite their broken families, hermitlike social lives and (in Jesse's case) involvement with gangs and drugs, the two became geeks par excellence, teaching themselves how to disassemble hard drives, debug operating systems, dispatch their foes at Quake and use the Net to find jobs and an apartment half a continent away. Jesse, academically underqualified but passionate and thoughtful, argues his way into the University of Chicago, while the brooding loner Eric lands a high-paying technical support job at Andersen Consulting.

These are the days of the Geek Ascension, Katz is persuaded: "The outcasts are coming inside. After a long and bitter persecution, they are taking their rightful place at the center of society—valuable, in touch with one another, even appreciated." One only has to visit Silicon Valley to see how right he is. The geeks who drive every startup and run every IT department are being rewarded with status, stock options and even envy. The Internet hasn't become a lifeline to every bright, lonely, angry kid; it certainly didn't help Eric Harris and Dylan Klebold. But Katz's poignant book reminds us what the computer revolution is supposed to be about.

The Bio Biz

FROM ALCHEMY TO IPO: THE BUSINESS OF BIOTECHNOLOGY
by Cynthia Robbins-Roth
Perseus Publishing, 256 pp., $25



IT OFTEN SEEMS THAT WALL Street picks the latest "hot" tech stocks based on little more than a sexy name. In the biotechnology arena, especially, there's a surfeit of both sexy names (Ariad, Biomatrix, Mitotix, Valentis) and uninformed investors. When President Bill Clinton and British Prime Minister Tony Blair issued a joint statement in March endorsing the immediate release of raw DNA sequence data by labs doing genomic research, flighty investors assumed that the two governments planned to restrict the patenting of human genes, sending the stocks of firms such as Celera and Incyte into a nosedive. In fact, both Britain and the United States already openly share genetic data. Investors "don't understand what they're investing in," one industry expert told *Science* magazine.

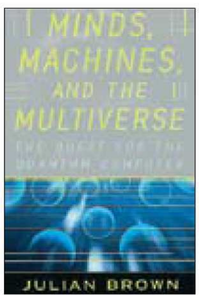
For any trader with an attention span longer than seven days (the average churn time for stock in Amazon.com, according to *Business Week*), Cynthia Robbins-Roth's new book should make it possible to buy and sell biotech stocks more intelligently. Robbins-Roth is a former Genentech scientist, a biotech columnist for *Forbes* and the founder of BioVenture Consultants, which advises venture capital firms. She describes the combination of daring, ingenuity and luck that helped mavericks like Genentech, Amgen and Genzyme put the industry on the map in the 1970s and 1980s, then explains how the giant pharmaceutical companies have come to dominate the labs, clinics and boardrooms where the contest for biotech profits is played today. Biotech, which accounted for more than half of the $6 billion earned by the top nine biopharmaceutical companies between April 1998 and March 1999, "has evolved into the research and development force supporting the drug industry," she observes. That means investors need to pay attention to a company's science and to the products in its pipeline.

Mindful that her audience's high-school biology may be rusty, Robbins-Roth starts with the basics, but quickly accelerates to such arcana as biochips, signal transduction and antisense therapy. She tells how these approaches can lead to new drug candidates and identifies the companies working on each. Then she details the long ordeal a biotech company must endure before a new drug can become a money-maker, from finding big pharma partners to suc-

ceeding in safety and efficacy trials. While it's hard for any outsider to judge a new drug's chances, Robbins-Roth's pointers should at least help investors decide whether, as she puts it, "a news item is devastating or merely an expected hiccup on the way to FDA approval."

Quantum Incoherence

MINDS, MACHINES, AND THE MULTIVERSE: THE QUEST FOR THE QUANTUM COMPUTER
by Julian Brown
Simon & Schuster, 396 pp., $30



ACHIEVING AND SUSTAINING "coherence" is one of the toughest problems in quantum computing. What makes quantum computers powerful is that they store information not in the form of classical bits—1 or 0—but as "qubits." Thanks to the uncertainty principle, qubits act as if they possess an infinite range of values between 0 and 1, enabling a system with only a few qubits to carry out huge calculations in a single stroke. But this state of "superposition" exists only if the physical system representing the qubits is "coherent," that is, isolated from the outside environment. The slightest interference causes superposition to collapse.

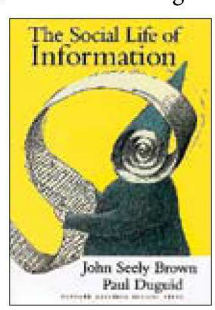
Apparently, coherence is also a challenge for books about quantum computing. When I reviewed Gerard Milburn's *The Feynman Processor,* I found it a titillating but insufficient introduction to the topic. Sad to say, Julian Brown's *Minds, Machines, and the Multiverse* errs on the opposite extreme, providing more history, circuit diagrams, mathematics and philosophical speculation than I was able to keep straight.

Souls with more patience than I have will profit from Brown's explanations of different ways to encode quantum states, the new logic gates and error-correction methods required to carry out useful quantum computations and the like, all of which seem thorough. (Though my confidence in the author decreased by a qubit when he identified Creon Levit, a researcher at NASA Ames Research Center, as "Leon Crevitt," and when he placed Ames itself in Palo Alto; it's at Moffett Field.) In an excellent chapter on encryption, Brown gives the clearest account I've seen of public-key cryptography, how unexpected advances in factoring large numbers jeopardize the security of even the longest (128-bit) encryption keys now in common use, and why quantum computers could blow factorization-based security algorithms to smithereens.

But Brown's true interests lie in more ethereal questions. If the behaviors of particles in coherent quantum states can be hijacked to carry out certain kinds of computations, is it possible that physics itself is computational—or, to put it another way, that the universe is a vast computer, calculating the arc of every fly ball literally "on the fly"? If so, who programmed the universe—God? What are we to make of the many-universes hypothesis favored by quantum-computing pioneer David Deutsch, in which a qubit's intermediate states are interpreted as discrete realities, each inhabiting a different universe? All of this, while intriguing, is hard to relate back to the very real question of whether silicon-chip manufacturers can keep Moore's Law going for another decade. I'm still looking for a take on quantum computing that doesn't decohere.

Swatch Beat

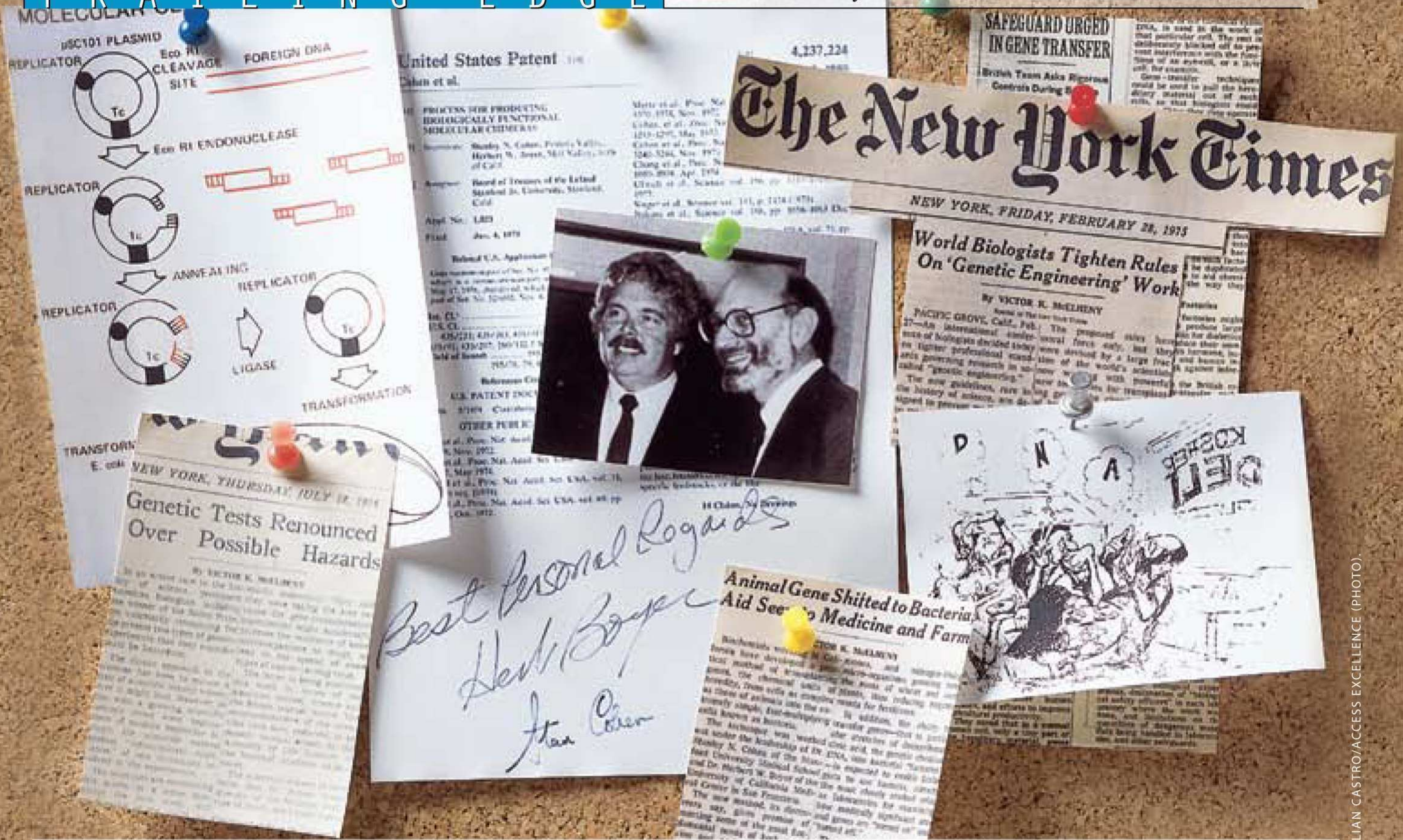
THE SOCIAL LIFE OF INFORMATION
by John Seely Brown and Paul Duguid
Harvard Business School Press, 320 pp., $25.95



I RECENTLY BOUGHT A SWATCH wristwatch that displays "Internet Time." In Internet Time the day is divided into 1000 "beats" lasting 1 minute, 26.4 seconds each. Beat 000 falls at midnight in Biel, Switzerland, where MIT Media Lab director Nicholas Negroponte helped Swatch inaugurate the new system in 1998. The institution of local time, Negroponte argued, is a confusing encumbrance in an era of instant global communication. "The digital world will make our lifestyles more asynchronous," he said. "For many people, real time will be Internet Time."

I find Internet Time entertaining, though I often catch myself trying to convert it in my head back to local standard time, which rather defeats the point. But John Seely Brown and Paul Duguid would call Internet Time a sinister example of "tunnel design"—the enshrining of fluid, borderless information without the supposedly dead weight of its original social, organizational or institutional contexts. Many parts of the new digital infrastructure, they argue in *The Social Life of Information,* are being built and marketed by "infoenthusiasts" for whom individuals and information are the basic units of existence. "From this viewpoint, value lies in information, which technology can refine away from the raw and uninteresting husk of the physical world," they write. A concept like time, however, is inescapably physical. The system of time zones has been in use since the 1880s because most of us prefer to organize our days around local noon, when the sun is overhead.

Brown, the director of Xerox PARC, and Duguid, a historian and social theorist at Berkeley, give a range of similar, well-documented examples in their book. Telecommuting has not spread as fast as expected, they sensibly conclude, because even the most wired employees still need face-to-face contact and frequent technical support. Digitization has not brought about the paperless office because it's still far easier to determine the importance, provenance and proper use of a paper document than an electronic one. New organizational processes introduced by reengineering frequently fail because they ignore the individual practices that actually keep businesses running. And so on. "New techniques and technologies often aim to remove a surface constraint (objects, organizations, practices, institutions) without appreciating their submerged resourcefulness," Brown and Duguid sum up. For this kind of technological reality check, it's not a Swatch beat too soon. ◊



VITO ALUIA. SOURCES: THE NEW YORK TIMES (NEWS CLIPPINGS), SCIENTIFIC AMERICAN (DIAGRAM), SANDRA BLACK AND LILIAN CASTRO/ACCESS EXCELLENCE (PHOTO).

The Birth of Biotech

Herbert Boyer and Stanley Cohen started a revolution

IN THE FALL OF 1972, THERE WAS NO SUCH THING AS genetic engineering. A late-night snack and a newspaper clipping changed all that—and spawned a new industry.

In the early 1970s, Herbert Boyer's lab at the University of California, San Francisco, isolated an enzyme that cut DNA at specific locations. At the same time, Stanley Cohen's Stanford lab was working out methods for introducing small circular pieces of DNA called "plasmids" into bacteria, which act as living Xerox machines, copying genes each time the microbes divide. At a November 1972 conference in Hawaii, both researchers presented their work—and realized that if they combined their techniques they would have a remarkable tool. The pair sealed the deal at a local deli and within months their labs had jointly proved the possibility of gene "cloning": splicing a gene of interest—say, one that encodes a human hormone—into a microorganism or other cell. The technique is at the heart of DNA sequencing, genetic engineering and, indeed, biotechnology.

Stanford seized on the potential of the work, and did something that was quite unusual at the time: They patented the technique. But that might not have happened if it weren't for a 1974 *New York Times* story on Boyer and Cohen's accomplishment by *TR* board member Victor K. McElheny, then the *Times*' technology writer. Clipped by Stanford's news director, the story landed on the desk of the school's director of technology transfer, Niels Reimers. Reimers quickly called Cohen; patents must be filed within a year of the first public disclosure of an invention, and Boyer and Cohen had published their results in 1973. By the time all of the researchers and institutions involved agreed on a strategy, Reimers had only a week to file.

In 1980, Boyer and Cohen received the first of three patents. All told, the patents generated over $250 million in royalties before expiring in 1997. Meanwhile, Boyer did one more critical thing for the burgeoning biotech industry: In 1976, with venture capitalist Robert Swanson, he founded the now-giant Genentech. ◊

Technology Review welcomes suggestions from readers for Trailing Edge.
If yours is selected, you will win a year's subscription to TR. This story was written with help from Stanley Cohen and from Sally Smith Hughes of the University of California, Berkeley's Bancroft Library.
Send a few paragraphs to: Trailing Edge, Technology Review, MIT Building W59-200, Cambridge, MA 02139; or e-mail: trailingedge@techreview.com.

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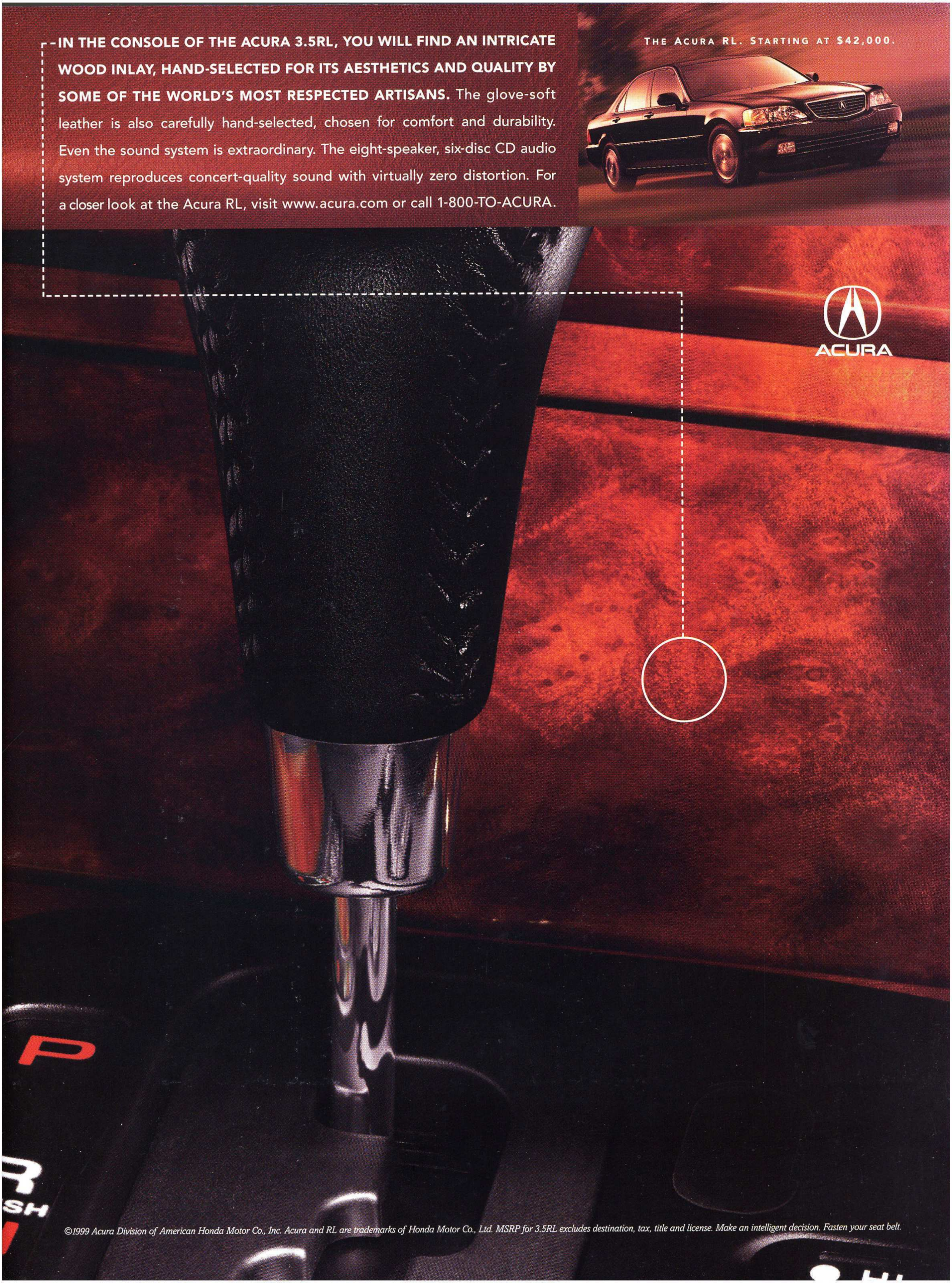
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